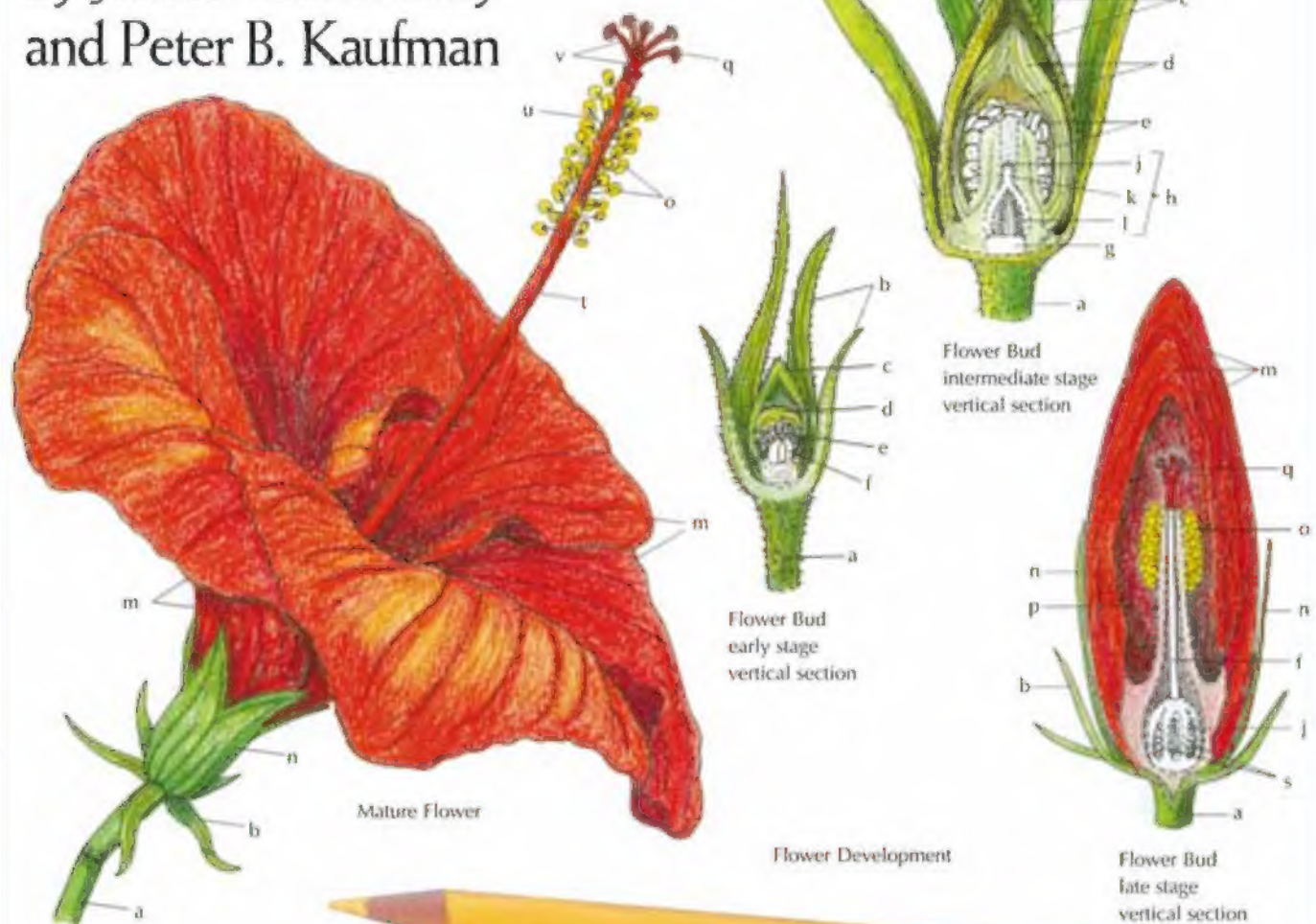


BOTANY ILLUSTRATED

Introduction to Plants,
Major Groups,
Flowering Plant Families

by Janice Glimn-Lacy
and Peter B. Kaufman

SECOND EDITION



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Preface

This is a discovery book about plants. It is for everyone interested in plants including high school and college/university students, artists and scientific illustrators, senior citizens, wildlife biologists, ecologists, professional biologists, horticulturists and landscape designers/architects, engineers and medical practitioners, and physical therapists and their patients. Here is an opportunity to browse and choose subjects of personal interest, to see and learn about plants as they are described. By adding color to the drawings, plant structures become more apparent and show how they function in life. The color code clues tell how to color for definition and an illusion of depth. For more information, the text explains the illustrations. The size of the drawings in relation to the true size of the structures is indicated by $\times 1$ (the same size) to $\times 3000$ (enlargement from true size) and $\times n/n$ (reduction from true size).

The contents reflect a balanced selection of botanical subject matter with emphasis on flowering plants, the dominant plants of the earth. After a page about plant names and terms, the book is divided into three sections. The first is an *introduction to plants*, showing structure and function; then, *major groups*, providing an overview of the diverse forms; and lastly, one-seventh of the *flowering plant families*, with the accent on those of economic importance. The sequence in the sections is simple to complex (cell to seed), primitive to advanced (blue-greens to flowering plants), and unspecialized to specialized (magnolias to asters and waterplantains to orchids). Where appropriate, an "of interest" paragraph lists ways these genera are relevant in our lives (categories include use as food, ornamentals, lumber, medicines, herbs, dyes, fertilizers; notice of wild or poisonous; and importance in the ecosystem). "Of interest" sections in *Botany Illustrated*, second edition, have been expanded to include many more topics of interest.

Evolutionary relationships and the classification of plants have been undergoing many changes in the past two decades since the first edition. In this edition controversial categories have been eliminated allowing individuals to be exposed to current thinking on plant classification. Classification from this second edition may be found in the Index under "Fungi Kingdom" and "Plant Kingdom." Pages on bacteria have been eliminated and two new pages on plant fossils, with accompanying illustrations, have been added. Every text page has undergone extensive revision.

For those interested in the methods used and the sources of plant materials in the illustrations, an explanation follows. For a developmental series of drawings, there are several methods. One is collecting several specimens at one time in different stages of development; for example, several buds and flowers of a plant (see 29) and button to mature forms of mushrooms (see 50, 51). Then, some are cut open to observe parts and decide how to present them, while others are to use for final drawings. Another method is waiting for the plant to change, which involves "forcing" stems (see 14), germinating seeds (see 40), watching one leaf expand (see 69), and drawing a flower in one season and its mature fruit in another (see 104, 109, 110, 111). An alternative to waiting for fruit is to use a collection of dry or frozen specimens, so that as spring flowers appear, the later maturing fruits can be seen at the same time (see 102, 105, 106).

In the first section, *introduction to plants*, there are several sources for various types of drawings. Hypothetical diagrams show cells, organelles, chromosomes, the plant body indicating tissue systems and experiments with plants, and flower placentation and reproductive structures. For example, there is no average or standard-looking flower; so, to clearly show the parts of a flower (see 27), a diagram shows a stretched out and exaggerated version of a pink (*Dianthus*) flower (see 87). A basswood (*Tilia*) flower is the basis for diagrams of flower types and ovary positions (see 28). Another source for drawings is the use of prepared microscope slides of actual plant tissues. Some are traced from microscope slide photographs such as cross-sections, vascular bundles, and transections. Scanning and transmission electron micrographs are traced for chloroplasts, amyloplasts, trichomes, internodes, and pollen grains. Preserved museum specimens provide the source for animals in the pollination series. The remainder of the drawings are from actual plants found in nature, the grocery store, plant nurseries, farm fields, botanical gardens, florist shops, and suburban yards.

In the *major groups* section, three pages have hypothetical diagrams, indicated in the captions. Other microscopic forms are from observations of living material or prepared microscope slides. For plants not locally available, dry-pressed herbarium specimens are measured for drawings (*Stylites*, *Helminthostachys*, *Gnetum*, and *Ephedra*) or machine-copied and traced (habit drawings

of filamentous algae) or chemically revived to three dimensions (bryophytes) for drawing with the use of a dissecting microscope. Drawings are also made from liquid-preserved specimens (*Tmesipteris* habit, *Welwitschia* and *Ginkgo* reproductive structures). For the majority of this section's drawings (including *Welwitschia* habit), living organisms are used.

For the *flowering plant families* section, except for two indicated diagrams in the grass family, all the drawings are from actual plants gleaned from fields, forests, roadside ditches, bogs, neighbors' yards, botanical conservatories, florist shops, grocery stores, and our gardens. The bumblebee arrived of its own accord.

Janice Glimn-Lacy
Peter B. Kaufman

Color Code Clues

The illustrations may be colored by using the easy-to-follow *Color Code*. Each drawing has lines from structures to letters, duplicated in the *Color Code*. All structures similar to the one with a line and letter are the same color; for example, only one of five petals may be identified. Colored pencils are recommended for pleasing results. My personal preference is Berol Prisma-color pencils. The colors needed are 2 shades of red, green, and blue, and 1 each of orange, yellow, pink, purple, brown, and black. Sometimes the *Color Code* lists double colors such as yellow-green, red-brown, or purple-green. Color the same area with a light touch of both colors for the closest resemblance to the plant's natural color. A black pencil used lightly provides a gray color. White is to remain blank. Using pink over light purple results in a lavender color. So as not to color areas that are to remain white or have small areas of color, follow the order listed in the *Color Code* for an individual drawing. Letters, missing from the *Color Code*, are in the text. They usually indicate structures shown as black outlines or colorless areas.

When drawing a 3-dimensional object, scientific illustrators traditionally use an upper-left light source on the object, which casts shadows on the lower right. Converting those shadows into ink dots (stipple) and lines (hatch) within the drawing outline creates an illusion of depth. Another aid to realism in black-and-white drawings is to show foreground structures as darker and larger than background ones. Obvious examples using this technique are the pitcher-plant leaves (see 91) and the iris flower and leaves (see 129). We see colored objects as brighter and more distinct when near

and as muted and less distinct when distant. Accordingly, by the use of bright shades of colors for foreground structures and muted shades for background structures, your colored pictures will appear more 3-dimensional. Darker shades of a color on the dot-and-line shadow areas will add to the effect.

To avoid having a green book, the illustration of foliage has been kept to a minimum with an abundant variety of colors indicated throughout. In the *introduction to plants* section, there is uniformity of a designated color. For example, water-conducting tissue and cells (xylem) are always color-coded blue, so that as you look at your colored pages, you see how water moves within a plant. For enlarged flower drawings in the *flowering plant families* section, true colors of flower parts are indicated in the *Color Code*. Dotted lines indicate where structures have been cut, show "see-through" areas, or separate color areas. Some lines are close together, others are single lines to color, but a color overlap of the lines will not detract from the over-all result.

Begin with the first page, which explains the names used, then choose any page that strikes your interest. If a flowering plant structure is new to you, it would be most helpful to look over the structure of the stem (14), leaf (21, 23), flower (27, 28), and fruit types (38, 39). Then, you will be ready to explore. Some discoveries are seeing how an apple flower matures into an apple (see 99), finding that grape flowers have flip-top petal caps (see 104), and learning that inside a common garden sage flower is a mechanical "arm" for sticking pollen on visiting bees (see 113).

Acknowledgements

We wish to thank the following colleagues of The University of Michigan for their contribution and review of specific topics: Dr. Joseph Beitel, lycopods; Dr. Michael Carleton, bats; Dr. Allen Fife, lichens; Dr. Michael Huft, euphorbs; Dr. Thomas Rosatti, heaths; Dr. Ann Sakai, maples; Dr. Alan Simon, birds; Dr. Wm. Wayt Thomas, sedges; Dr. Kerry S. Walter, orchids. Also, we would like to thank the following University of Michigan Botany Faculty in the Department of Botany (now, Department of Ecology and Evolutionary Biology and Department of Molecular, Cellular, and Developmental Biology); Dr. Howard Crum, bryophytes; Dr. Harry Douthit, bacteria; Dr. Robert Shaffer, fungi; Dr. William R. Taylor, algae; Dr. Edward G. Voss, grasses; and Dr. Warren H. Wagner, Jr., ferns, plus access to his extensive plant collections; the staffs of the University Herbarium, Museum of Natural History and University Science Library for advice, loans of resource materials, use of microscopes, books and other printed materials. Dr. P. Dayananadan was especially generous with his excellent scanning electron micrographs. For assistance in obtaining rare and out-of-season living plants, we thank William Collins, Jane LaRue, and Patricia Pachuta of the University of Michigan Matthaei Botanical Gardens. We also thank Dr. David Darby of the University of Minnesota for his review of geological information. For palms, we thank Dr. Ackerman of the Garfield Conservatory, Chicago. For locating regional plants, we appreciate the assistance of Robert Anderson, Patricia and Terrance Glimn, Marie Mack, Lorraine Peppin, Ellen

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Lastly, we express our special appreciation to our families—Jack, John, and Jim Lacy and Hazel, Linda, and Laura Kaufman.

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BOTANY ILLUSTRATED



Introduction to Plants,
Major Groups,
Flowering Plant Families

SECOND EDITION

Names and Terms

Division. The major category is called a division and is equivalent to phylum in the animal kingdom. Division name endings indicate plants (-phyta) and fungi (-mycota). In the top illustration are some examples of Magnoliophyta, the flowering plant division. The endings of lesser categories indicate class (-opsida), subclass (-idea), order (-ales), and family (-aceae). Classification of one specific plant is shown.

Class. Flowering plants are divided into 2 classes: Magnoliopsida, the dicots (2 seed leaves), and Liliopsida, the monocots (1 seed leaf). A seed leaf is the first leaf to emerge from an embryo in the seed (see 40). In the second illustration are examples of Liliopsida, the monocot class.

Family. The third group of plants shows some monocots in the lily family, Liliaceae (see 128).

Genus Species. Next are 3 lilies in the **genus** *Lilium*. A plant type is given a 2-part scientific name – a generic name, the genus, which is a noun and is always capitalized, and a specific epithet, the **species**, which is usually an adjective. For example *officinale* means medicinal and is commonly used for herbs. Sometimes a species is named for a person. A species that is not named is written as sp. (plural: spp.).

In a written list of species in the same genus, it is only necessary to fully write the genus once at the beginning. The genus of species that follow is indicated with the first letter of the genus followed by a period. For example: *Mammillaria albescens*, *M. bocasana*, *M. columbiana*.

The 2 parts of the name, called a **binomial**, are italicized in print and underlined when handwritten. The binomial is sometimes followed by a name abbreviation of the person who first described the plant in botanical literature. For example, the most common is Linnaeus, the Swedish botanist, indicated by an L.

One of the reasons the scientific name of a plant may change is because it is discovered that someone else named the plant earlier. The newly found name is published in Latin. Another reason a name may change is that the plant is reclassified into a different group. There may also be many forms of a plant with separate species names, when later, it is decided they are all the same species.

The specific lily here is *Lilium michiganense*, with the English common name Michigan Lily. A spontaneously occurring variation of a species in nature also may have a **variety** (var.) name (see 101). An X between the genus and new specific epithet (see 77) indicates a hybrid between 2 species. Hybrids may occur in nature or be derived by plant breeding. Intergeneric hybrids have a combined name of the genera with a capital X at the beginning. For example, X *Heucherella* is a hybrid between *Heuchera* (pink to red flowers) and *Tiarella* (white flowers) and has pale pink flowers.

Common Names. As names differ from region to region, a plant may have many common names. For example, *Amelanchier* may be commonly named serviceberry, shadbush, or June-berry. Sometimes a common name is used for unrelated plants. So to be universally understood, botanists use the binomial system of naming plants in Latin. A plant variety that exists only through cultivation has a common **cultivar** name (cv., **cultivated variety**) (see 93).

Habit vs. Habitat. The gross **habit** refers to the appearance of an individual plant in its entirety. Where a plant grows in its environment is called the **habitat**, such as a beech-maple forest, a pond, a prairie, or a desert.

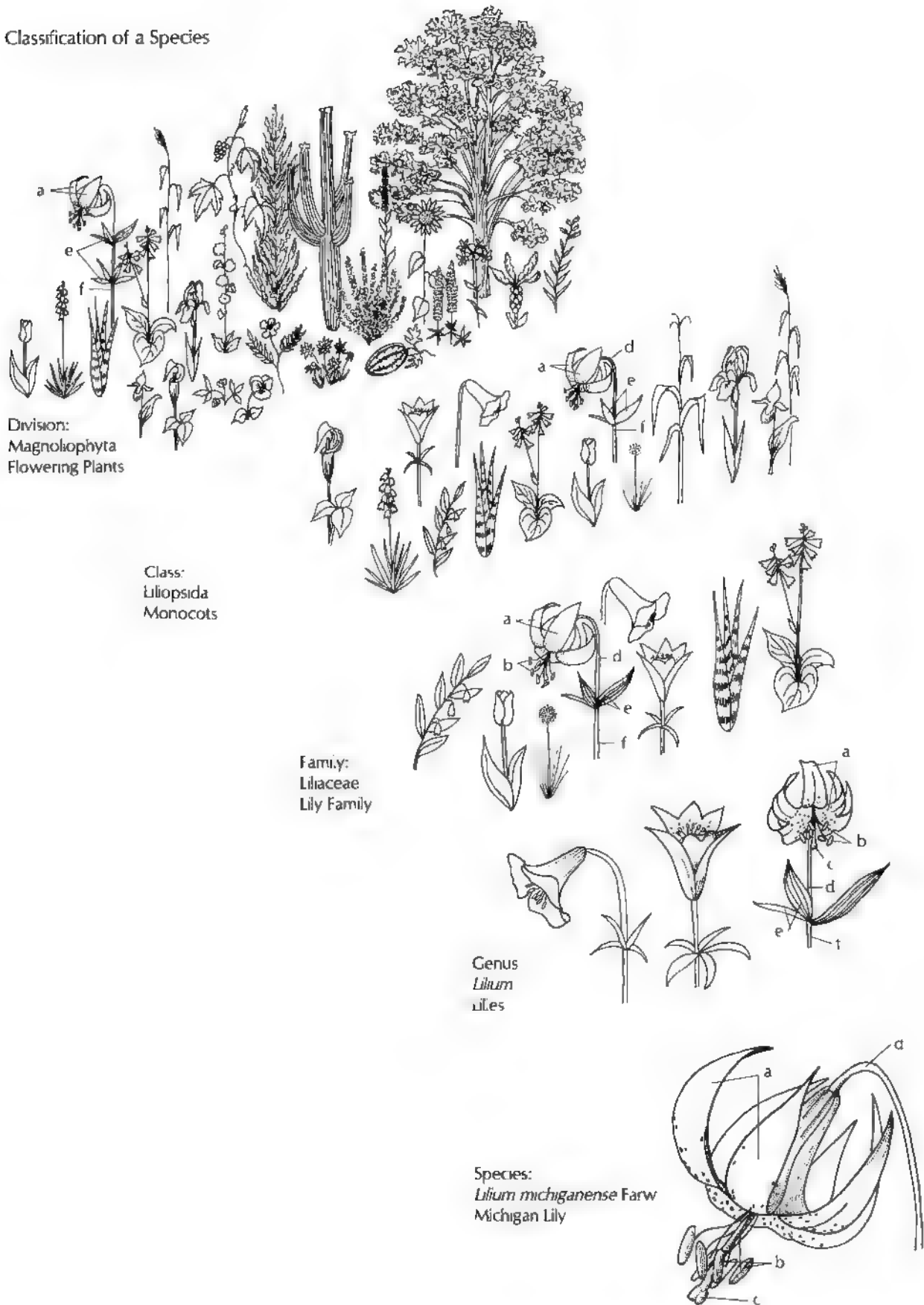
Herbaceous vs. Woody. Herbs have little or no secondary vascular tissues and their above-ground shoots usually die back at the end of the growing season. Herbs are considered to be more advanced in evolution than woody plants (shrubs and trees) with secondary vascular tissues (secondary xylem and phloem) present, which persists in growth year after year in stems and roots.

Macroscopic vs. Microscopic. If a plant structure can be seen with the unaided eye, it is designated macroscopic; if a microscope is used to observe it, it is microscopic in size.

COLOR CODE

orange:	tepals (a) (see 27)
brown:	stamens (b)
light green:	stigma (c)
green:	peduncle (d), leaves (e), stem (f)

Classification of a Species



Cell Structure

Parts of a Cell

Cell Wall. The cell wall (a) encloses and protects the cell contents and plays a vital role in cell division and cell expansion. Composed of overlapping cellulose microfibrils, other polysaccharides and varying amounts of lignin, the cell wall is a relatively rigid structure in mature cells. It may vary in thickness and has pits that function in communication between cells. The region between the primary walls of adjacent cells, the middle lamella (b), is composed of a cementing substance called pectin.

Other substances that may be present in the cell wall are gums, resins, silica, calcium carbonate, waxes and cutin, and both structural protein and enzymes (which are also proteins). There may be intercellular spaces (c) between walls of bordering cells.

Pits. Primary pit fields (d) are thin areas in the cell wall with tiny strands of cytoplasm, called plasmodesmata (s), connecting one cell with another. Pits are important in facilitating the flow of water and mineral nutrients between conducting cells in the xylem vascular tissue (see 11).

Plasma Membrane. A semipermeable membrane (e) encloses the cytoplasm within a cell. It is composed of variable amounts of fat type molecules (lipids) and proteins, and has within it channels for the movement of ions such as potassium (K^+), calcium (Ca^{2+}), and hydrogen (H^+).

Cytoplasm. The cytoplasm (cytosol, f) is a liquid, gel-like substance and contains several types of organelles; smooth (g) or rough endoplasmic reticulum (h), rough referring to attached ribosomes (i) on the ER (endoplasmic reticulum) and free ribosomes.

Vacuole. In a mature plant cell, one large vacuole usually occupies most of the space within the cell. It is sur-

rounded by a single-layered membrane, the tonoplast (j), and contains cell sap composed of water, sugars, and various organic and inorganic solutes. It may, in some cells such as in beet roots and flower petals, contain water-soluble pigments. The vacuole functions in regulation of osmotic balance and turgidity of the cell, and it stores secondary metabolites.

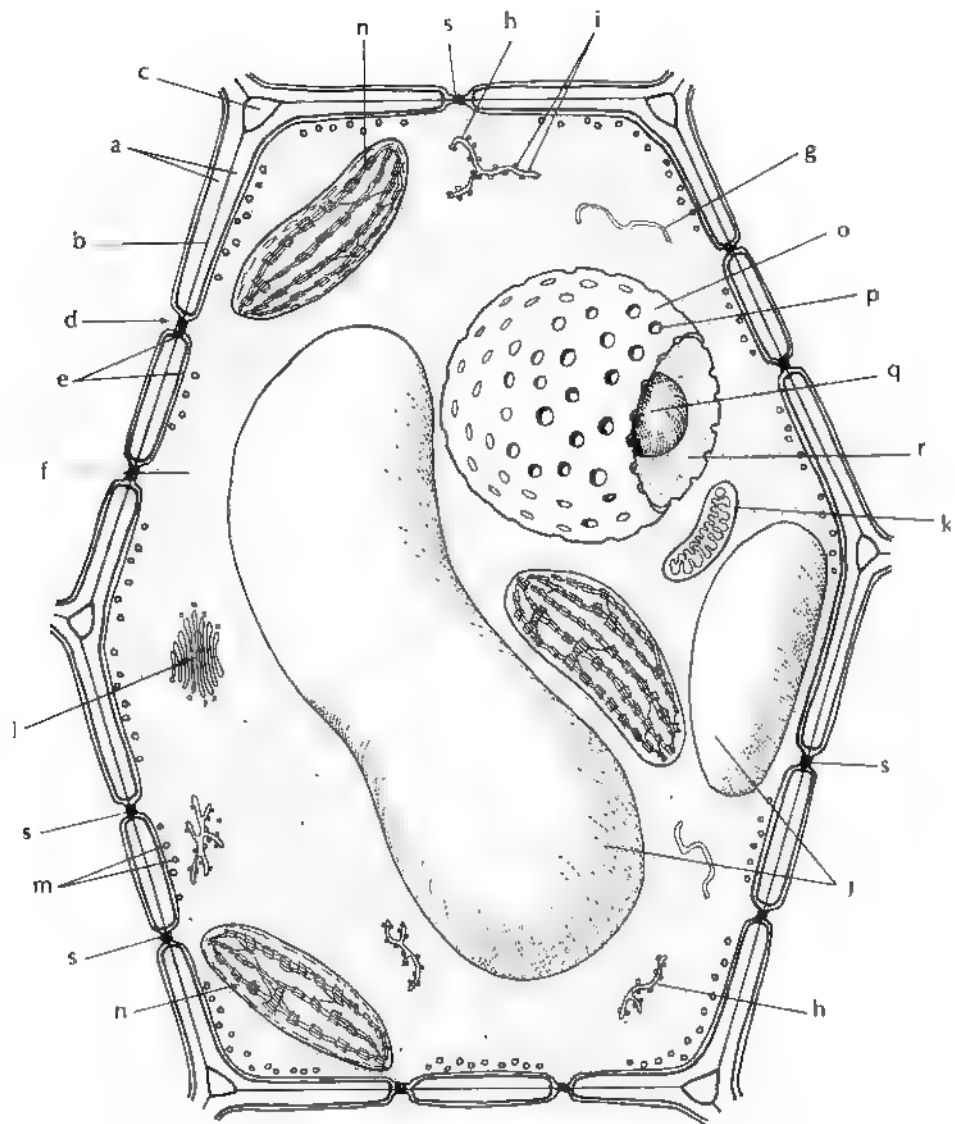
Organelles. Within the cytoplasm are mitochondria (k), dictyosomes (Golgi bodies), microbodies, and microtubules (m). Microtubules are represented by an array of parallel tubular tracks and facilitate movement of proteins and organelles within the cell. The ER is a system of tubes and sacs, that work with dictyosomes to produce and secrete compounds and deliver specific proteins and membrane lipids to their proper locations within a cell.

Also, there may be plastids such as chloroplasts (n), leucoplasts, and chromoplasts; and non-living substances of water-soluble products or reserve substances such as oil droplets, protein bodies, and crystals (see 3).

Nucleus. The nucleus is enclosed by a double membrane (o) that has pores (p) in it to allow communication with the cytoplasm (f). Within the nucleus are chromosomes, which contain DNA needed to create proteins within the cell. Chromosomes are only visible during cell division (see 6 and 7). Also present in the nucleus are one or more nucleoli (q) containing RNA. The rest of the nucleus is filled with nucleoplasm (r). The information needed to create the entire plant is within the nucleus, mitochondria, and chloroplasts of each cell.

COLOR CODE

tan:	cell wall (a), middle lamella (b), dictyosome (l)
colorless:	intercellular space (c), pit field (d), plasma membrane (e), vacuolar membrane (j)
purple:	smooth ER (g), rough ER (h)
black:	ribosome (i)
green:	chloroplast (n)
blue:	mitochondrion (k)
orange:	microtubules (m)
red:	nuclear membrane (o), pore (p)
gray:	nucleolus (q)
pink:	nucleoplasm (r)
yellow:	cytoplasm (f), plasmodesmata (s)



Generalized Plant Cell
diagram

Cell Organelles

The cytoplasm (cytosol) of a plant cell contains various organelles with specific functions. With the use of a transmission electron microscope (TEM), which shows structures magnified thousands of times, these organelles can be viewed individually. The organelles represented here are not shown in proportion to one another.

Plastids. Plastids are classified by the primary pigment they contain. Young cells have undifferentiated plastids (proplastids), which can multiply by simple division. They develop into the various kinds of plastids characteristic of mature cells.

Chloroplast. This plastid (a) is where photosynthesis takes place. In higher plants it is usually oval-shaped and is surrounded by a double membrane (b). Within it are sac-like structures (shown cut in half) called thylakoids (c). A stack of thylakoids is called a granum (d), and this is where green chlorophyll pigments are located. Chlorophyll and proteins bound to the thylakoids use light energy to make simple sugars from carbon dioxide and water (photosynthesis, see 24).

Extensions from some thylakoid membranes form interconnections between grana. The thylakoids also contain accessory pigments, carotenoids, and xanthophylls. In the stroma (e) of the chloroplast are DNA, RNA, oil droplets (f), ribosomes (g), and other materials such as starch grains, found in chloroplasts of green plant tissues that have been actively photosynthesizing.

Leucoplast. Such colorless plastids contain storage products, which include oils, protein bodies, or starch

grains. In plant parts with a high starch content, such as potato tubers or rice grains, a leucoplast that contains starch grains (h) is called an amyloplast (i).

Chromoplast. These plastids are colored red (k), orange (l), or yellow (m), depending on the pigments they contain. In the changing colors of ripening fruit such as a tomato or a red pepper, the chloroplasts (green) differentiate into chromoplasts (orange to red). As fruit color changes, so do plastid structure, pigment types, and content.

Mitochondria. These organelles are surrounded by a double membrane (n). The inner of these two membranes (o) has infoldings, called cristae (p), that protrude into the cavity within. Mitochondria are the primary sites of enzymes controlling cell respiration (a chemical release of energy from sugar or other metabolites). They can replicate by simple division and, like chloroplasts, they contain DNA.

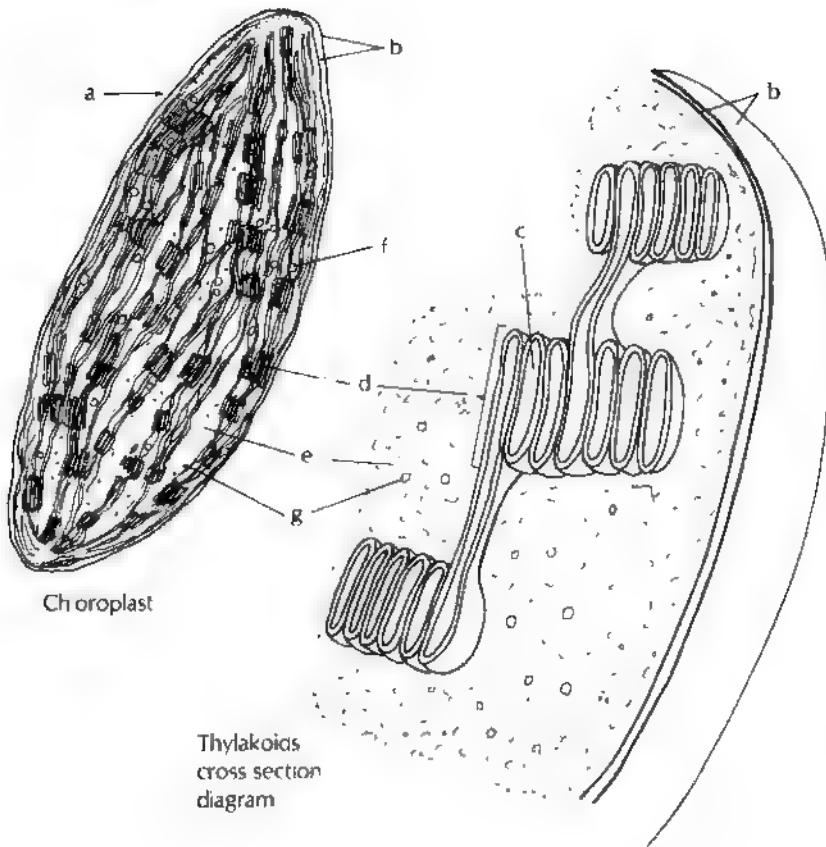
Ribosomes. Ribosomes (q) contain ribosomal RNA and function in protein synthesis. They are also found in cytoplasm, and associated with the endoplasmic reticulum (r) in the cytoplasm.

Dictyosomes (Golgi Bodies). These organelles appear as a stack of flattened sacs (s) and associated vesicles (t). Dictyosomes produce and secrete cell wall polysaccharide precursors and complex carbohydrate substances that are secreted out of root cap cells. This results in less injury to the growing root as it penetrates the soil.

COLOR CODE

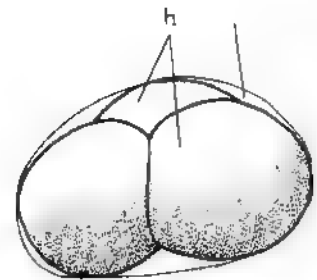
green:	chloroplast (a), thylakoid (c), granum (d)
white:	double membrane (b, n), stroma (e), starch grain (h), amyloplast (i)
yellow:	lipid (f), chromoplast (m)
black:	ribosome (g, q)
blue:	inner membrane (o), crista (p)
red:	chromoplast (k)
orange:	chromoplast (l)
purple:	endoplasmic reticulum (r)
tan:	dictyosome sacs (s), vesicles (t)

Cell Organelles

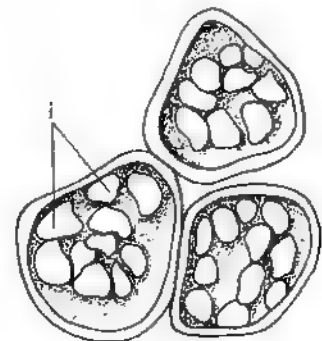


Chloroplast

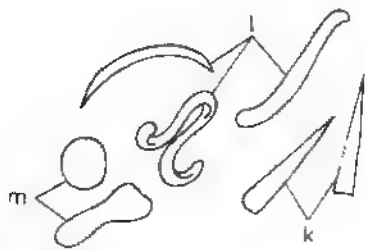
Thylakoids
cross section
diagram



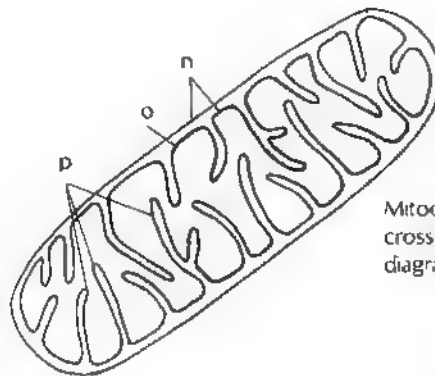
Amyloplast
with compound starch gran
 $\times 3000$



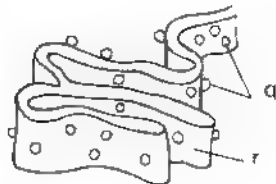
Amyloplasts
in parenchyma cells



Chromoplasts

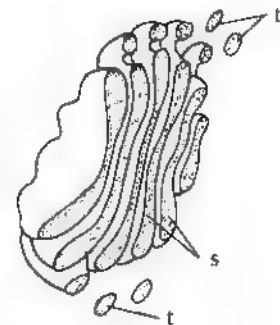


Mitochondrion
cross section
diagram



Rough ER
ribosomes on endoplasmic reticulum
diagram

Dictyosome
cross section
diagram



Cell Pigments

Chlorophylls. The chlorophylls are oil-soluble. **Chlorophyll a** (greenish-yellow in solution) is the primary photosynthetic pigment in green plants for the transfer of light energy to a chemical acceptor. Light that is absorbed provides the energy for photosynthesis (see 24). A green leaf absorbs blue light (mostly at 430 nm) and red light (mostly at 660 nm). It reflects the green wavelengths so as to appear green to us. Chlorophyll a, alone, is found in blue-greens and in some red algae. Accessory pigments in photosynthesis transfer light energy to chlorophyll a. One of these is **chlorophyll b** (blue-green solution), found in higher plants and green algae with chlorophyll a. **Chlorophyll c** is also an accessory pigment found with chlorophyll a in brown algae and diatoms. **Chlorophyll d**, together with chlorophyll a, is found in some red algae.

Carotenoids. These pigments are considered as accessory pigments in photosynthesis, when found in chloroplasts associated with chlorophyll, and as color pigments when found in chromoplasts. Carotenoids, like the chlorophylls, are not water-soluble. They absorb mainly violet and blue light between 400 and 500 nm, and they reflect red, orange, yellow, brown, and the green color of avocado fruit. They give color to carrot roots, tomato fruit, and many yellow flowers. Carotenoids of red and yellow are revealed in autumn leaves (h, l) after the green chlorophyll pigments begin to break down. This occurs when daylengths start to shorten and cooler temperatures prevail in temperate regions of the world. **Carotenes** (yellow or orange non-oxygen containing pigments) seem to function in the prevention of chlorophyll destruction in the presence of light and oxygen. β -carotene is the most important of the carotenes. **Xanthophyll** pigments are oxygen-containing carotenoids. They transfer energy to chlorophyll from light. Some of the xanthophylls include lutein, zeaxanthin, violxanthin, and fucoxanthin, which is found in brown algae.

Phycobilins. These pigments are water-soluble. As accessory pigments they absorb light and transfer excitation energy to chlorophyll a. The red pigment, **phycoerythrin**, is found in red algae. The blue pigment,

phycocyanin, is present in blue-greens and some red algae.

Phytochrome. This pigment plays an important role in regulating many processes of plant growth and development. Phytochrome is found in two reversible forms. One form, P_r , absorbs red light (mostly at 660 nm) and reflects a blue-green color. The other form, P_{fr} , absorbs far-red light (mostly at 730 nm) and reflects a light-green color. The highest amounts of phytochrome are found in meristematic tissues (see 9).

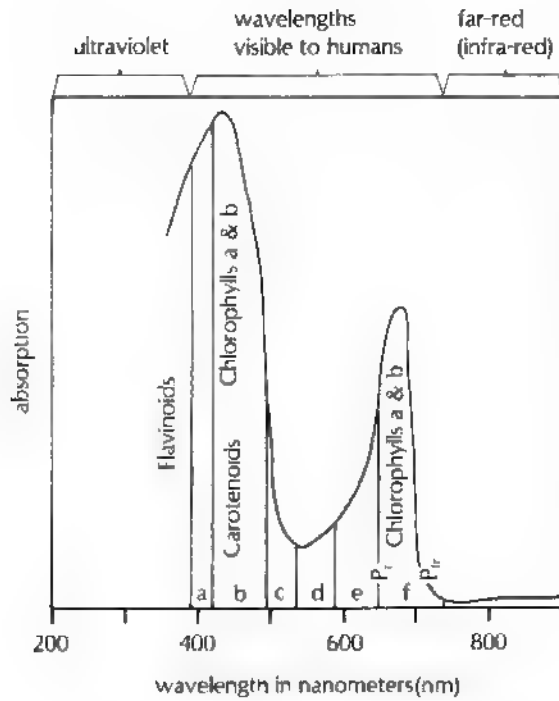
Flavonoids. These water-soluble pigments accumulate in cell vacuoles. They absorb ultraviolet wavelengths of light. **Anthocyanins** are phenolic pigments that are found in most fruits and in many flowers. These red-, purple-, and blue-reflecting pigments are seen in the red color of apple (*Malus*) fruit and geranium (*Pelargonium*) flowers; the blue of cornflowers (*Centaurea*) and larkspur (*Delphinium*); and the red and purple of *Fuchsia* (l, m) flowers. The function of these pigments can only be hypothesized, but study of plants having these pigments is useful in determining evolutionary relationships. **Flavins** often appear to us as yellow or ivory-colored flowers. Some flavins, such as riboflavin (vitamin B₂), act as co-factors in enzyme reactions and some are thought to be receptor pigments in the bending of plants toward light (phototropic responses; see 20).

Betalains. These are water-soluble, nitrogen-containing reddish pigments that are found in only 9 families of the flowering plant subclass, Carophyllidae (see 75). These pigments are water-soluble and found in the vacuoles of cells. **Betacyanin** appears as blue-violet to red and is found in beet (*Beta*) roots (n) and red cactus flowers. **Betaxanthin** pigments reflect yellow, orange, and orange-red.

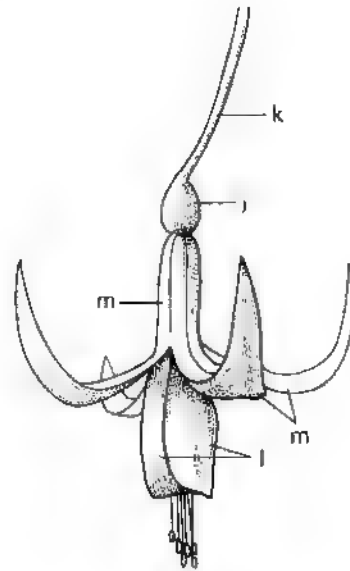
COLOR CODE

purple:	column a, petal anthocyanin (l)
blue:	column b
green:	column c, leaf chlorophylls (g), ovary (j), peduncle (k)
yellow:	column d, leaf carotenoids (i)
orange:	column e
red:	column f, leaf carotenoids (h), sepal anthocyanin (m)
blue-purple-red:	root betacyanin (n)

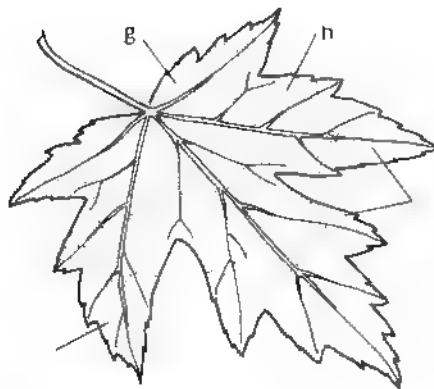
Pigments



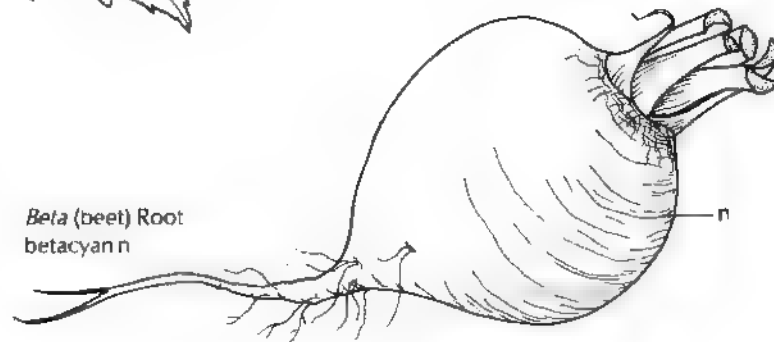
Light absorption of a Green Leaf



Fuchsia Flower
anthocyanins



Acer (maple) Leaf
chlorophylls
carotenoids



Beta (beet) Root
betacyanin

Cell—Water Movement

More than 90% of most plant tissues is composed of water. Water is needed for most life processes to take place. The movement of water (a) from cell vacuole (b) to another cell's vacuole (c) within the plant is by diffusion through the cell's semipermeable plasma membrane (d), which encloses the cytoplasm (e). The flow is from a region of high concentration of water to a region of low concentration of water, a process that is called **osmosis**. The more substances (solutes) dissolved in the water, the lower the concentration (water potential) of water. For example, in a leaf cell that is producing sugar (a solute, f) from photosynthesis, water passes into the cell. An osmotic equilibrium is reached when water no longer enters the cell.

Turgor Pressure

As water (a) passes into a cell, it expands the plasma membrane (d), exerting pressure against the cell wall (g). This is called **turgor pressure**. In fully inflated cells, turgor pressure is one of the key “driving forces” in plant growth. In cells of developing fruits, turgor pressure is very important for fruit enlargement, and indicates the necessity of keeping plants well watered during this period. Turgor pressure maintains the size and shape of plant parts such as leaves and flowers.

Plasmolysis

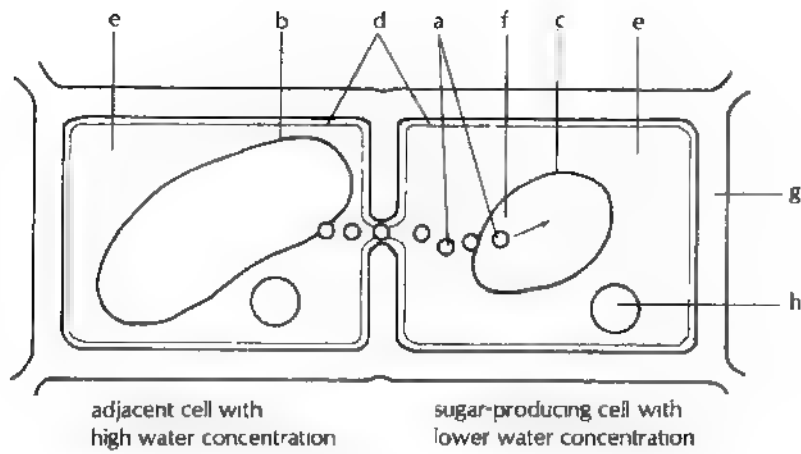
Water (a) is lost from a cell when there is a lower water concentration in adjacent cells that have more solutes present. Turgor pressure within the cell then decreases. When there is no turgor pressure, the plasma membrane (d) shrinks from the cell wall (g), leaving through the cell wall. This process is termed **plasmolysis** and is reversible when water is returned to the cytoplasm and vacuole through osmosis. Plasmolysis of cells results in wilting of plant shoots and is the opposite of fully turgid cells, where plants are fully “inflated” or crisp, like fresh celery.

“Wilting”

When excessive cell water (a) is lost through evaporation to surrounding dry air, “wilting” occurs. In this condition cell turgor pressure is lost, the plasma membrane (d) shrinks from the cell wall, and cell wall (g) contracts because there is no external solution to fill in between. This condition can result in plants that are “permanently wilted” if the wilting persists over a period of 10 to 12 days. If wilted plants are watered before they reach the permanent wilting condition, they regain turgor in several hours time.

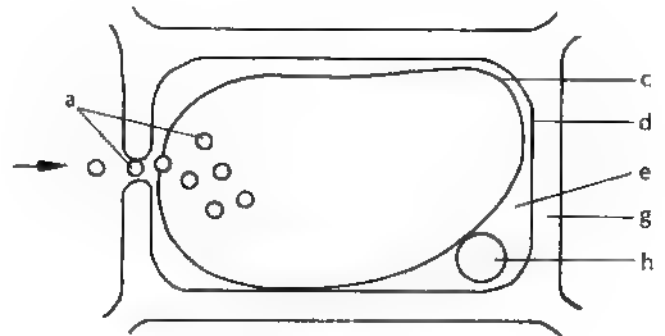
COLOR CODE

dark blue:	water (a)
colorless:	vacuole membrane (b, c), plasma membrane (d)
yellow:	cytoplasm (e)
light blue:	sugar solution (f)
tan:	cell wall (g)
red:	nucleus (h)
gray:	external solution (i)

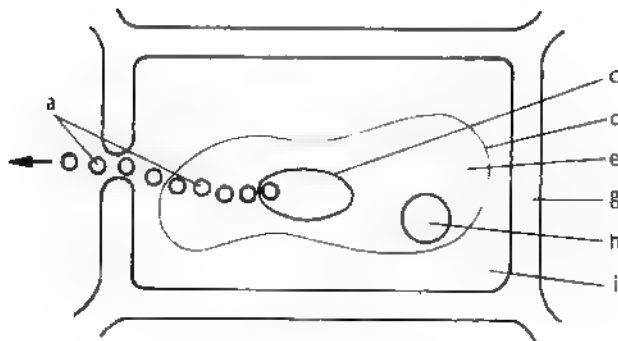


Water Movement
Between Cells

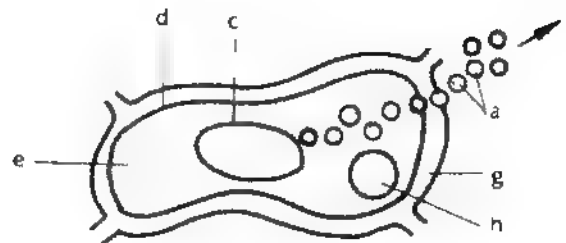
Osmosis



Cell inflated or Turgid
due to turgor pressure



Cell flaccid
due to plasmolysis



Cell from permanently
wilted plant

Cell Chromosomes

Chromosomes (a) are the darkly stained microscopic bodies in the nucleus which contain genetic information (genes) that determine inheritance characteristics of an organism. A chromosome basically consists of a core of DNA (deoxyribonucleic acid) surrounded by a jacket of basic protein called histone. Bacteria and blue-greens have no nuclei or chromosomes, but instead, have a DNA-bearing structure called a nucleoid (see 43). Some of their DNA may be in circular forms called **plasmids** (b).

Chromosome Structure. Chromosomes are composed of chromatin, which can be seen microscopically with the use of stains such as the Feulgen reagent or acetocarmine. Chromosomes are best observed during mitotic or meiotic division, when the chromatin is condensed and chromosomes visible (see 7, 30). Chromosomes have a simple external structure. A chromosome (a) has a small body called a **centromere** (c) with "arms" (d) on either side. The part of the centromere where spindle fibers are attached is called a **kinetochore**. Small segments, almost circular, that occur near the ends of a chromosome are called satellites (e).

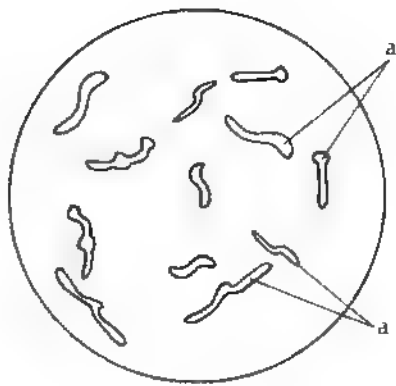
During mitosis and meiosis, the chromosome replicates into two strands called **chromatids** (f) attached together at the centromere. **Chiasma (crossing-over)** is when chromatids (f) overlap, break, and exchange segments with other chromatids (g) during meiosis. It may involve 2, 3 or all 4 chromatids. This can give rise to genetic variability or **mutations**.

Chromosome Number. Chromosome number is characteristic for the majority of vegetative (somatic) cells of an organism. This is called the $2n$ or **diploid number**. Organisms whose somatic cells contain multiple sets of chromosomes are called **polyploids**. These occur as a result of hybridization between sexually compatible parents with different chromosome numbers. Polyploidy is widely evident in plants, but is rare in animals.

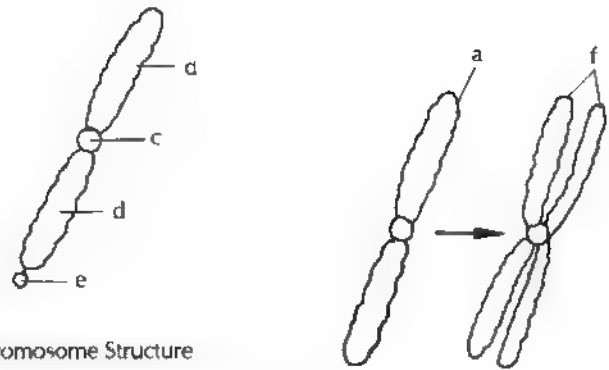
COLOR CODE

purple: chromosomes (a), centromere (c),
"arms" (d), satellite (e), chromatids (f)
blue: plasmid outline (b)
red: chromatids (g)
green: chromosomes (h)
black: chromosomes (i)

Chromosomes in nucleus

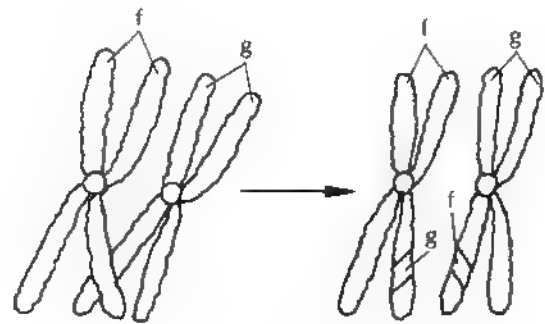


Cell Chromosomes



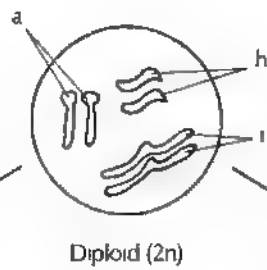
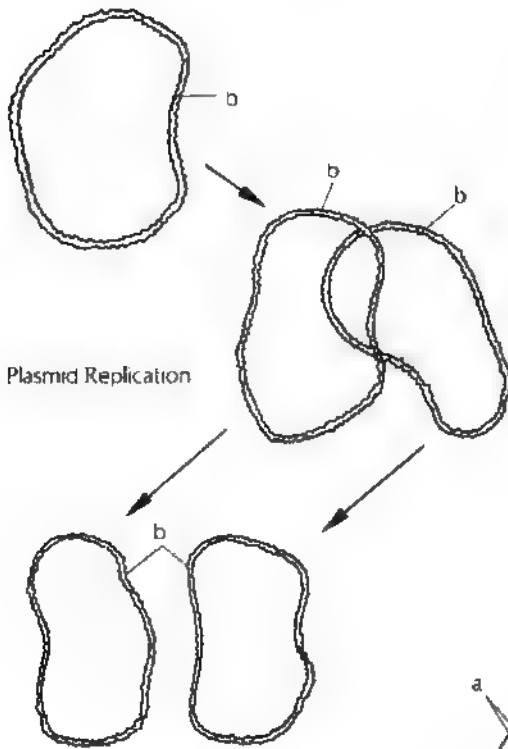
Chromosome Structure

Chromosome Replication



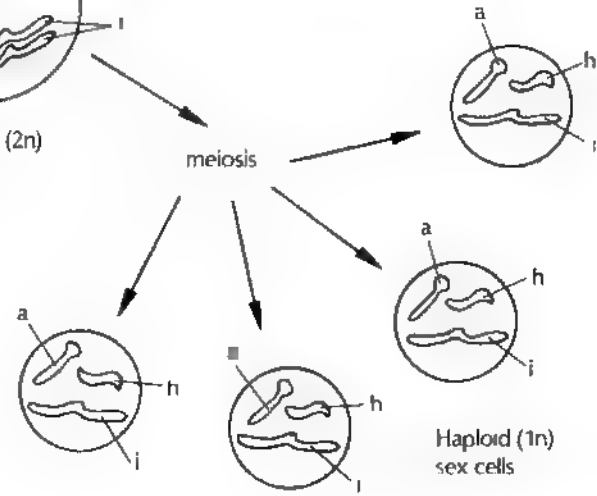
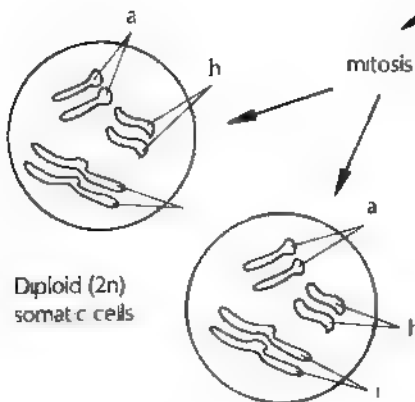
Chiasma involving 2 chromatids

Plasmid Replication



mitosis

meiosis



Cell—Mitosis

Mitosis is a process of nuclear division in which chromosomes divide lengthwise, separate, and form 2 identical nuclei. Mitosis is usually accompanied by cell division, which involves the formation of a new cell wall between the 2 identical nuclei. In plants, good sites to observe mitosis are in root tips, shoot apices, and newly developing leaves. This is done by making thin sections of the tissues, mounting them on slides, staining them with acetocarmine or Feulgen stains, then observing the sections with the high power or oil immersion lens of an optical (light) microscope.

The Cell Cycle

The period when the nucleus is between divisions is called **interphase**. During interphase is a period of replication of cytoplasmic organelles, followed by a period when chromosomes (a) are duplicated, then a period when spindle fibers (bundles of microtubules) are made. Phases of mitosis are **prophase**, **metaphase**, **anaphase**, and **telophase**. Interphase and the 4 phases of mitosis constitute the cell cycle.

Phases of Mitosis

Prophase. At the first stage of mitosis, the chromosomes (a) become visible as long threads. For clarification only 3 chromosomes are shown. On each strand

is a small body called a **centromere** (f). Then the chromosomes start to shorten and thicken and divide into 2 helical coiled strands called **chromatids** (g). DNA is replicated half to each chromatid.

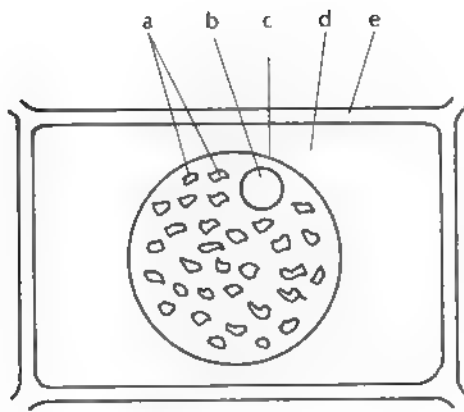
Metaphase. In stained cells on microscope slides, the nuclear membrane and nucleolus (b) can no longer be seen during metaphase in vascular plants. Metaphase is marked by the appearance of the spindle (h). It is at this time that the chromosomes migrate to the spindle and the centromeres (f) align in a flat equatorial plane. The pairs of chromatids (g) are held together at the centromeres (f).

Anaphase. Anaphase is initiated with division and separation of the centromere, providing each chromatid with centromere (f). This phase ends with the chromatids, which are now called chromosomes, moving to opposite poles (i) of the spindle (h).

Telophase. This phase begins with the chromosomes (a) completing their movement to the poles. It ends with the chromosomes once more becoming diffuse, as in interphase. A new nuclear membrane (c) forms around each group of chromosomes (a) and nucleoli (b) reappear. During interphase, a new cell wall (e) forms between the nuclei.

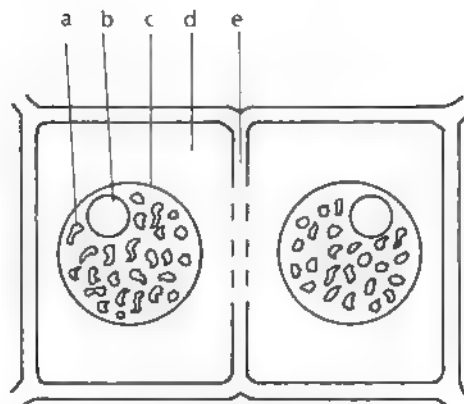
COLOR CODE

purple: chromosomes (a), centromere (f),
 chromatid (g)
gray: nucleolus (b)
red: nuclear membrane (c)
yellow: cytoplasm (d)
tan: cell wall (e)
orange: spindle (h)

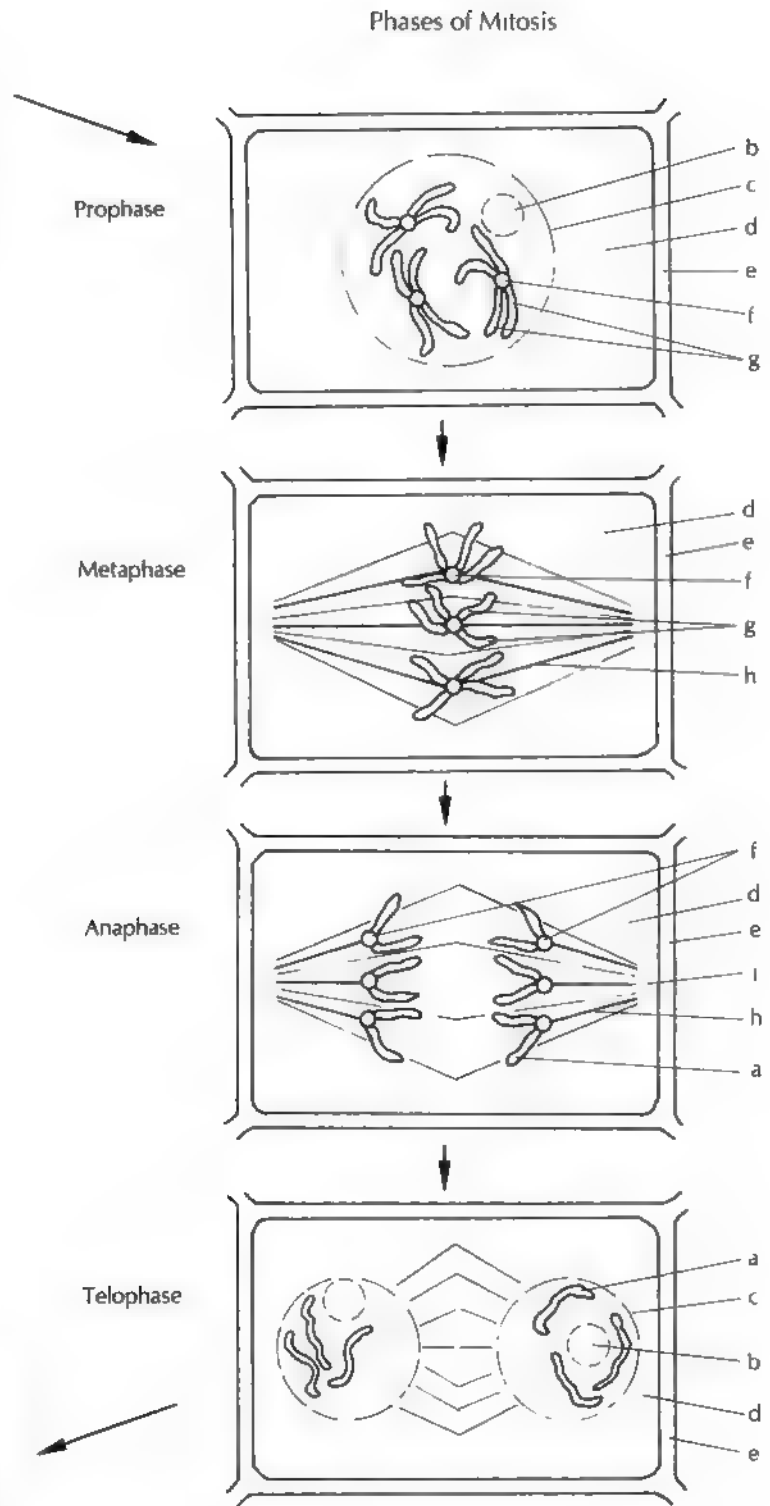


Interphase

Cell - Mitosis



Interphase



Cell Types

Parenchyma Cells

Parenchyma cells (a) make up the major portion of the primary plant body. They are usually thin-walled and vary in shape from spherical with many flat surfaces, to elongated, lobed, or folded. As living cells that are unspecialized initially, they later differentiate to more specialized cells. Parenchyma cells are found in photosynthetic tissue of green leaves and green stems, in epidermis, below the epidermis in cortex (b), in pith, and in the vascular system.

As food storage cells, they occur in specialized organs such as bulbs and tubers, in seeds (as endosperm), and in seed leaves (cotyledons). Specialized parenchyma tissue (also called aerenchyma) with intercellular air spaces aids water plants in floating. Parenchyma cells may appear as secretory forms such as glandular and stinging hairs, nectaries, and salt glands.

Collenchyma Cells

Collenchyma cells (c) provide elastic support to stems and leaves due to variously thickened primary walls (d) containing cellulose, hemicellulose, pectin, and water. These closely arranged, living cells are short or elongated in shape. They are usually found near the surface in the cortex around vascular bundles (e) of leaf petioles and stems.

Sclerenchyma Cells

Sclerenchyma tissue cells function in mechanical support due to thick lignified secondary walls (f), which contain large amounts of cellulose and lignin. At maturity, some sclerenchyma cells no longer have living protoplasts. Fibers and sclereids are types of sclerenchyma cells.

Fibers (g) are elongated cells with pitted cell walls (h). They are found in water-conducting tissue, xylem (i) and food-conducting tissue, phloem (j), along leaf veins and margins, and surrounding vascular bundles in stems. Examples of commercial fibers are hemp, flax, jute, rattan, and cotton, used in making rope, mats and baskets.

Sclereids are dense (lignified), short cells which may look like stones, rods, bones, stars, or branched structures. Familiar forms, with dense cell layer of sclereids occur in nut shells, fruit pits, and the seed coats in

legume tree pods (Fabaceae, see 100). Pear (k) and quince fruits contain "stone cells" (l), that is, nests of sclereids in the fleshy mesocarp (m) tissue (see 39).

Vascular Cells

Cells of the xylem tissue, **tracheids** (n), are elongated, have bordered wall pits (o) for water conduction, and are aligned side by side. Also, water- and mineral-conducting cells of the xylem, namely, the **vessel elements** (p), have bordered pits (q) in their cell walls. The vessel elements are aligned end-to-end to form long tubes. The xylem sap passes vertically through the vessel elements via end perforations that may be parallel slits (r) or a single large opening (s). Conifers and primitive woody flowering have only tracheids for water conduction.

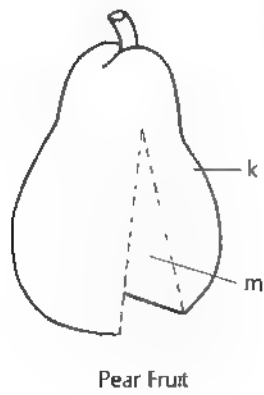
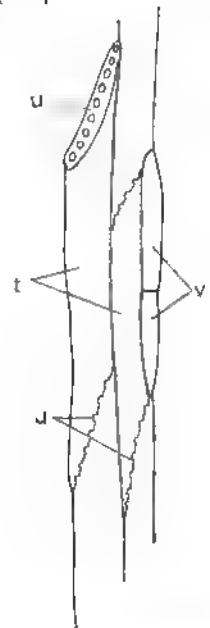
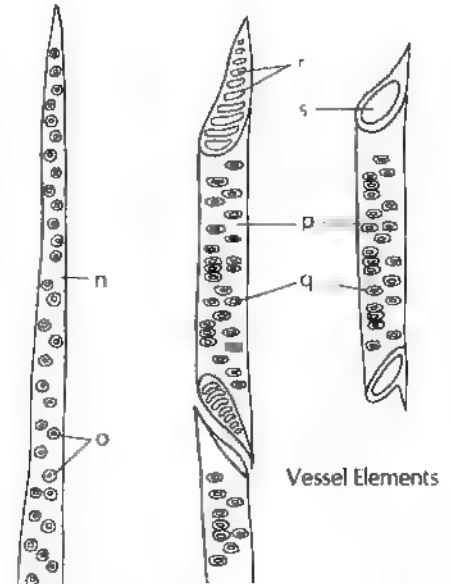
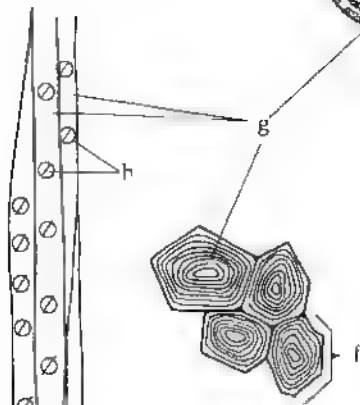
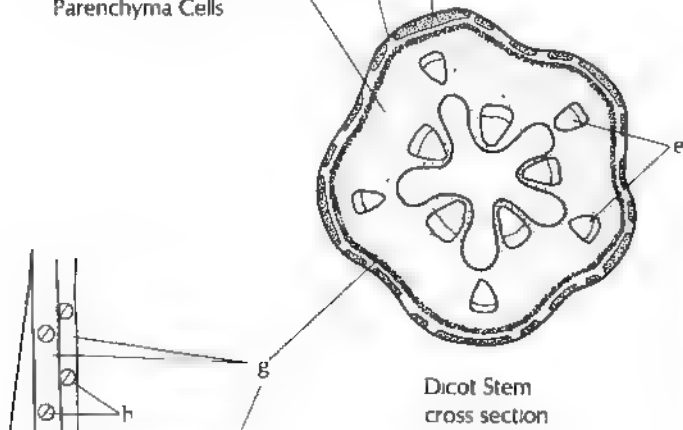
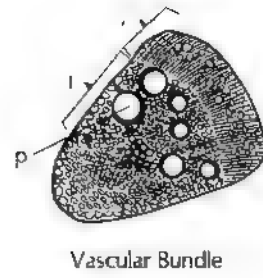
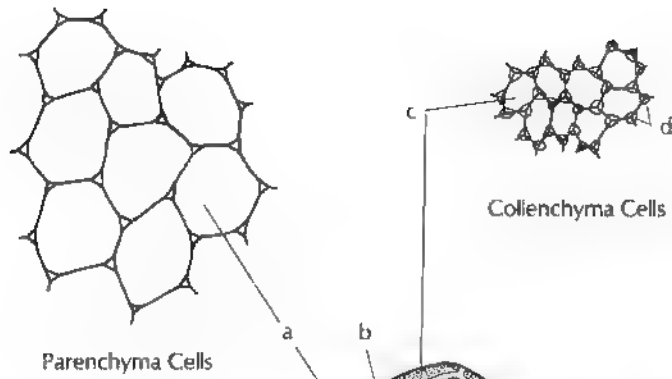
Sieve cells are enucleate (minus a nucleus), found in the phloem of conifers and primitive vascular plants such as ferns. The sieve cells are elongated and thin-walled. **Sieve-tube elements** (t) are enucleate and found in more advanced flowering plants. Both sieve cells and sieve-tube elements form long end-to-end columns called sieve tubes. Sieve plates (u), consisting of primary pit fields, occur in the end walls of sieve tube elements. In sieve cells, the walls, over their surfaces, contain localized sieve areas containing many pores that allow for cell-to-cell solute transport. Cell-to-cell connecting strands of cytoplasm pass through the sieve plates.

Companion cells (v), a specialized type of parenchyma, may be present in varying numbers in association with sieve tube elements.

COLOR CODE

green:	parenchyma cells (a), collenchyma cells (c)
light green:	parenchyma cortex (b)
white:	vascular bundles (e), xylem (i), phloem (j), mesocarp (m)
tan:	fibers (f, g, h)
yellow:	pear epidermis (k), sclereids (l)
blue:	tracheid (n, o), vessel elements (p, q, r, s)
orange:	sieve-tube elements (t), sieve plate (u), companion cells (v)

Cell Types



Tracheid

Sieve Tube Elements

Tissue Systems of the Plant Body

Cells in plants are arranged in tissues such as epidermis, cortex, and pith. Several tissues also make up a tissue system such as the vascular system.

Meristems

Throughout the life of a plant, new cells are continuously being formed at sites called **meristems**. Meristems consist of undifferentiated cells that are found at shoot tips, at root tips, in the vascular cambium, and in the cork cambium. Meristems produce cells that differentiate into specialized tissues of three systems: dermal, ground, and vascular. Only primary growth (left column), resulting from the activity of the shoot and root apical meristems, is found in some herbaceous dicots, most monocots, and lower vascular plants. Conifers and woody dicot shrubs and trees exhibit secondary growth (right column).

Shoot Tissue Systems

The shoot is the portion of the plant above the roots and is composed of stems, leaves, flowers and fruits. The stem apical meristem (a) forms leaf primordia (b) on its flanks and young stem tissues below during the vegetative phase, and in flowering plants, flower primordia during the reproductive phase.

Dermal Tissue System. The outer layer of the apical meristem gives rise to the epidermis (c) of the primary plant body. In the stems of plants with secondary growth, the epidermis is replaced by periderm (d), commonly called the "outer bark." Periderm consists of the meristematic cork cambium producing cork (phellem) outward and the pithoderm inward (see 15).

Ground Tissue System. The cells and tissues of the ground tissue system are derived from the apical meristem. In the diagram, ground tissue is manifest as cortex (e), located between epidermis and vascular bundles, and pith (f) in the center of the stem.

Vascular Tissue System. Also derived from the apical meristem, the procambium (g) initiates the vascular system with cells that differentiate inside into primary xylem (h), the water- and nutrient-conducting tissue, and outside into primary phloem (i), the food-conducting tissue. In plants with secondary growth, a persistent cambium, the vascular cambium (j), makes possible added layers

of secondary xylem (k) and phloem (l), resulting in an increase in stem diameter.

Root Tissue Systems

The root apical meristem (m) produces new root cap (n) cells ahead (below) of the root apex, as well as cells of the protoderm (young epidermis), ground meristem, and procambium back of the root apex.

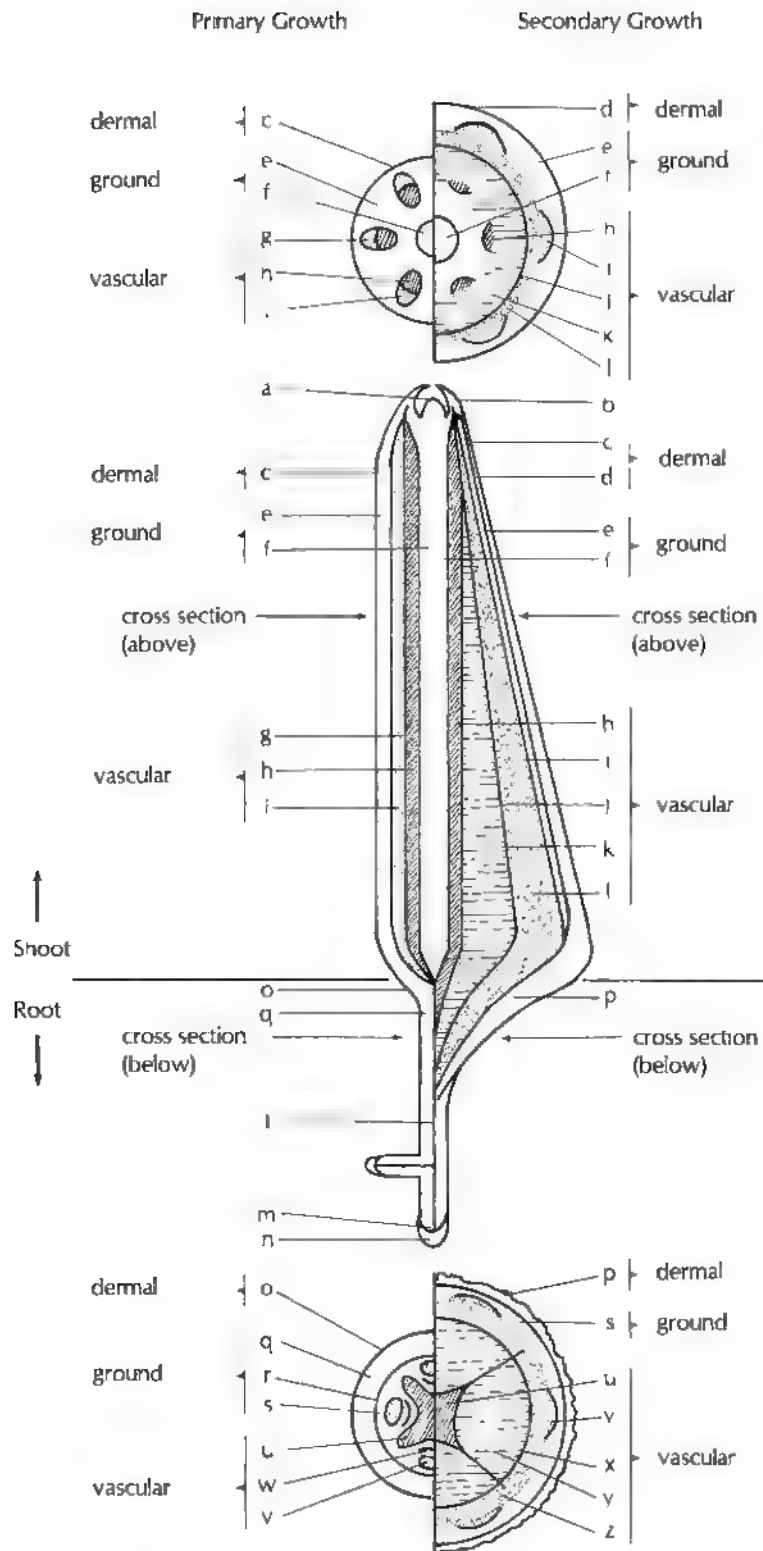
Dermal Tissue System. With primary growth, roots are covered with epidermis (o). With secondary growth, the epidermis and root hairs (derived from epidermal cells) are sloughed off because of formation of periderm (p) on the outside.

Ground Tissue System. Cortex (q) lies between the epidermis and vascular system in portions of roots undergoing primary growth. The innermost layer of cortex, the endodermis (r), bounds the pericycle tissue (s), which surrounds the primary vascular system. In portions of roots undergoing secondary growth, the cortex, like the epidermis, is shed as the periderm develops cork cells.

Vascular Tissue System. In the root, unlike the stem, the primary vascular system is in a central cylinder (t) with xylem and phloem arranged in an alternate radial manner. Primary xylem "arms" (u) radiate out from the center with alternate poles of primary phloem (v) in the outer portion of the cylinder. Between them is procambium (w). In older portions of roots, where secondary growth is evident, the vascular cambium (x) produces successive layers of secondary xylem (y) and phloem (z).

COLOR CODE

red dot:	apical meristem (a, m)
red line:	procambium (g, w), vascular cambium (j, x)
colorless:	epidermis (c, o), pith (f), root cap (n), endodermis (r), central cylinder (t)
green:	young leaf (b), shoot cortex (e)
blue:	primary xylem (h, u)
light blue:	secondary xylem (k, y)
orange:	primary phloem (i, v)
light orange:	secondary phloem (l, z)
tan:	root cortex (q), periderm (d, p)
yellow:	pericycle (s)



Tissue Systems of the Plant Body

Tissue—Epidermis

Usually a single layer of cells (a) makes up the epidermis that covers roots, stems, leaves, and fruits. At the outer surface of the epidermal cells is a continuous layer (cuticle, b) made up of fatty material (cutin). It is sometimes overlaid with a protective, waterproof coating of wax. Oil, resin, and salt crystals may also be deposited on the surface. Functions of the epidermis include mechanical support, protection from desiccation (drought) and against attack by virulent pathogenic organisms and insects, gas exchange, restriction of water loss by evaporation (transpiration) through stomates and water and mineral storage.

In a surface view, the epidermal cells appear hexagonal, elongated, or wavy-margined (c) like jigsaw puzzle pieces. Shape varies with the plant part being examined, such as root, stem, leaf (d), flower parts (e), or fruit. Some plants such as those in the grass family (Poaceae), have parallel rows of elongated cells (f) alternating with short specialized silica (g) and cork (h) cells, stomata (i) and trichomes. Pits (j) are present in the elongated cells.

Guard Cells. In stomata, pairs of guard cells (k), specialized epidermal cells, control air exchange (CO_2 and O_2) and water loss from plants by changing the size of the pore (stoma, l) that separates their inner walls. A pair of guard cells can expand or contract as a result of changes in turgor pressure. Usually, as guard cells develop high turgor pressure, stomata open, and with reduced turgor pressure, they close. The stomatal pore (l) allows gas exchange to occur between outside air (m) and inner plant (n) tissues. Other cells, called subsidiary cells (o), may be associated with guard cells.

Trichomes (Hairs). The epidermis may have various extensions of one- or many-celled hairs (trichomes, r) some of which may be glandular. Glandular excretions include terpenes (essential oils, carotenoids, saponins, or rubber), tannins, or crystals (such as salt).

Fragrance in flowers is provided when essential oils in the petals vaporize. Non-glandular hairs may be found on any shoot surface as well as on seeds such as cotton (see 90) and willow (see 95).

Menthol in mints is produced in hairs on the leaves. It is the primary flavoring constituent of peppermint too. Many members of the mint family (Lamiaceae, see 113) and aster family (Asteraceae, see 119) produce terpenes in hairs in leaves and stems that repel herbivores like deer. The glandular hairs on bracts of the female flowers of hops produce humulone that is responsible for the bitter principle in beer.

The leaves and stems of hemp or marijuana (*Cannabis sativa*) are covered with hairs that contain over 20 different cannabinoids responsible for hallucinogenic properties of this plant. These constituents also help in treating patients with glaucoma and allaying the adverse side effects of chemotherapy in treating cancer.

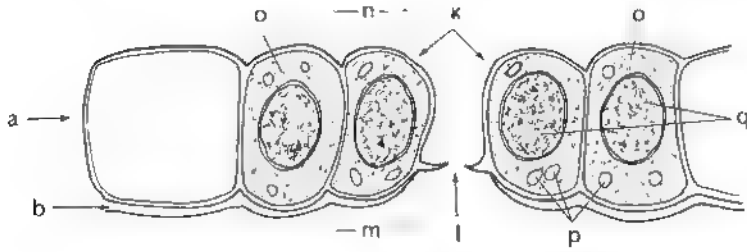
Nectar Glands. Nectar glands, found in various flower structures and on stems and leaves, produce a sugar solution. Some flowers have specialized scent glands (osmophors) in the form of flaps, hairs, or brushes. Glands on the surface of carnivorous plants produce nectar (s) or enzymatic digestive fluids (t).

Root Hairs. Root epidermal cells (u) function in the uptake of water and dissolved minerals. Most plant roots produce extensions from the epidermal cells of trichomes called root hairs (v). They occur above the elongation zone of the root. At maturity, root hairs collapse as the epidermal cells are sloughed off. Alternatively, they may remain intact due to lignification of their cell walls. But even these root hair cells may disappear as bark forms on the root in more mature regions.

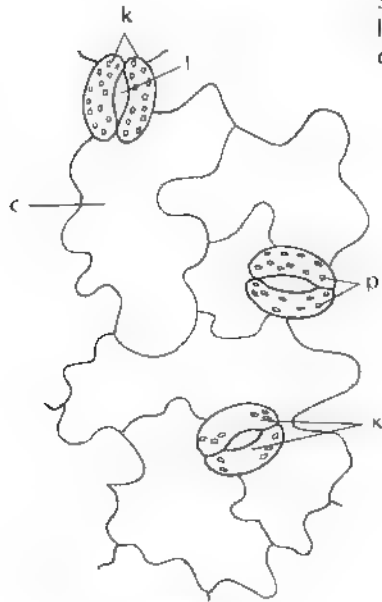
COLOR CODE

colorless:	cells (a, c, d, e, f, k, o, t, u), pits (j)
yellow:	cuticle (b)
gray:	silica cells (g)
tan:	cork cell (h)
green:	chloroplast (p)
red:	nucleus (q)
optional:	trichomes (r, s, v)

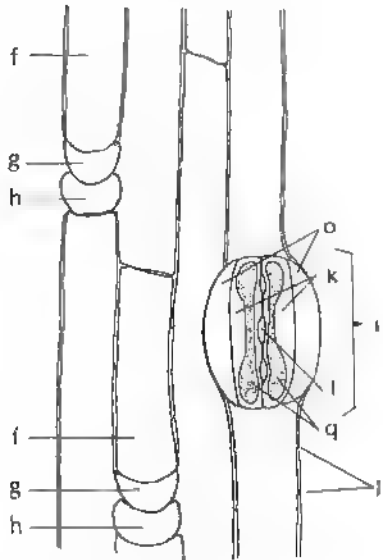
Epidermis



Stomatal Apparatus
leaf epidermis
cross section

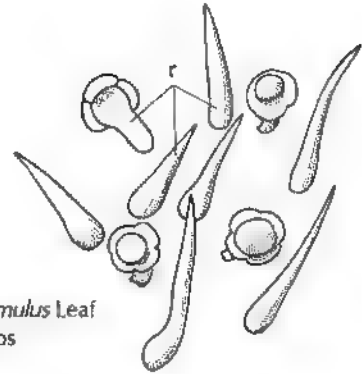


Epidermis
leaf, lower surface
(dicot)

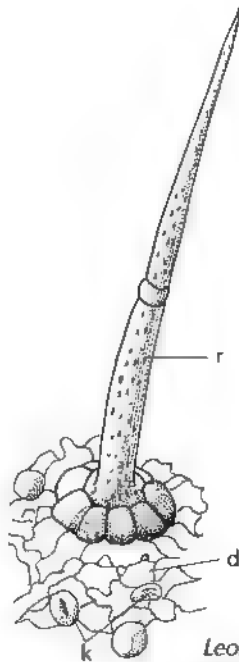


Epidermis
stem internode
(grass, a monocot)

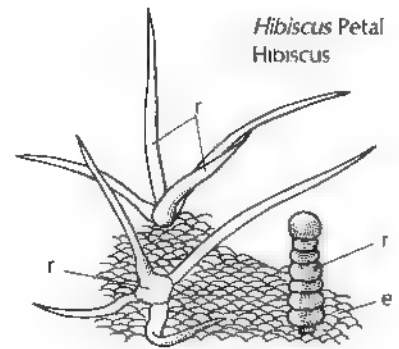
Trichomes



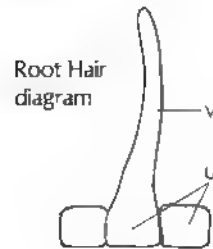
Humulus Leaf
Hops



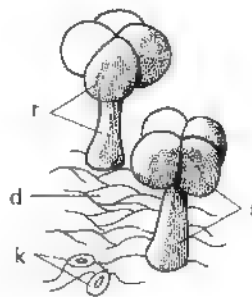
Leonurus Leaf
Motherwort



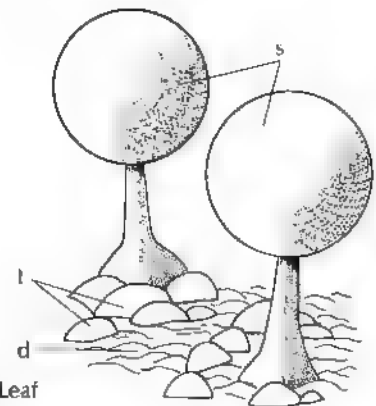
Hibiscus Petal
Hibiscus



Root Hair
diagram



Solanum Leaf
Potato



Pinguicula Leaf
Butterwort

Tissue—Primary Vascular System

In the primary plant body, the vascular system is made up of vascular bundles composed of conducting elements, interspersed with fibers for support and parenchyma cells for food storage. Procambial cells (a) give rise to primary xylem toward the inside and primary phloem toward the outside of the plant. In most monocots, after differentiation of vascular elements, no procambium remains.

Xylem: Water-conducting Tissue

Several types of cells (living and non-living) make up xylem tissue: tracheary elements (b), composed of tracheids (c) and vessel elements (d), which conduct water and nutrients; fibers (e), which provide support; and living parenchyma cells (f), which store food. Sclereids may also be present. In monocots, vessel elements, whose walls have been stretched and broken by elongation, result in spaces (lacunae, g) in the xylem.

Bordered Pits. The primary walls of tracheids and vessel elements have depressions called primary pit fields. When secondary walls (h) are formed, the bordered holes (pit apertures, i) consist of a pit chamber (j) and a pit membrane (k). Of two adjacent cells, the pits of each are at the same level forming pit-pairs. Composed of the primary wall of each of the two adjacent cells, the pit membrane is permeable and allows passage of water and mineral nutrients from cell to cell.

Phloem: Food-conducting Tissue

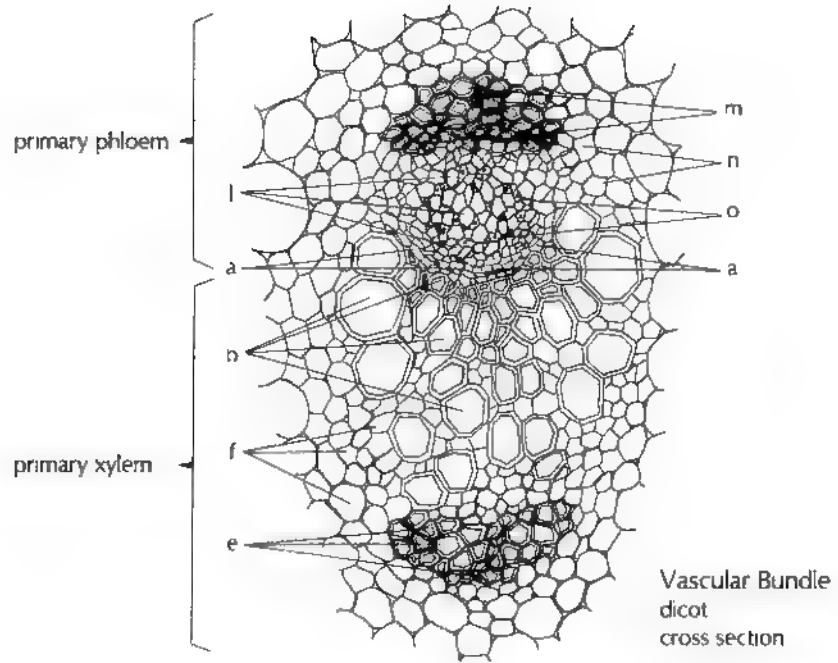
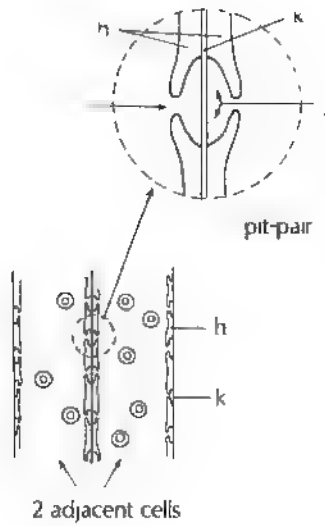
Phloem tissue is composed of sieve elements of sieve cells or sieve tube elements (o) for food conduction, fibers (m), and parenchyma cells (n). Companion cells (s) are associated with sieve tube elements. Latex-producing cells (laticifers) and sclereids may be present.

(Dicot vascular bundle adapted with permission: Esau, K., *Plant Anatomy*, 1967, John Wiley & Sons.)

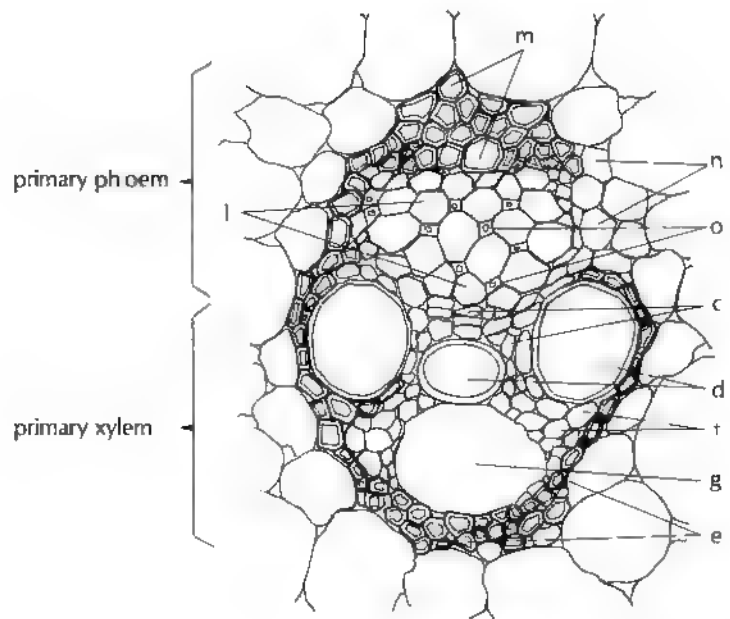
COLOR CODE

red:	procambial cells (a)
colorless:	parenchyma cells (f, n), lacuna (g), pit membrane (k), secondary wall (h)
blue:	tracheary elements (b, c, d)
tan:	fibers (e, m)
orange:	sieve tube elements (l), companion cells (o)

Bordered Pit



Vascular Bundle
dicot
cross section



Vascular Bundle
monocot
cross section

Root Types and Modifications

The **root** is the underground organ of the plant. Its primary functions include uptake of water and minerals and anchorage of the above-ground (aerial) portions of the plant.

Root Types

In conifers and dicots, a primary root (a), called a radicle in the seed embryo, develops lateral branching roots (b). As this system develops further, the individual roots may show secondary growth due to cambial activity. The **cambium** is a meristem that produces secondary xylem, and secondary phloem (see 9).

In many monocots, the first-formed roots of the seedling, called **seminal roots**, eventually die. They are replaced by **adventitious roots** (d), which emerge from the stem. Dicots may also have accessory adventitious roots, for example, the aerial roots on vines such as ivy (see 16).

Root Modifications

Storage Roots. Plants may develop specialized, thickened roots, as those found on carrot (*Daucus*, f), beet (*Beta*), sweet potato (*Ipomea batatas*, see 112), man-root (*Ipomea pandurata*), tuberous begonia (*Begonia*), and dahlia (*Dahlia*). These roots are an adaptation for food storage and are seen in many biennials and perennials. A **biennial plant** is one that produces leaves the first year and flowers and fruit the second year, then dies. A **perennial plant** lives for more than two years.

Prop Roots. Some plants develop supporting roots as found in corn (*Zea*, h) and mangrove (*Rhizophora*). Such roots are especially effective in anchoring the shoot system in the soil, preventing them from capsizing in strong winds, heavy rains, and impact from predators and human activities.

Contractile Roots. Contraction, or shortening of some roots, helps pull down and anchor the plant more firmly in the soil. Contractile roots (i) are common in herbaceous dicots and monocots, and occur in taproots, adventitious roots, and lateral roots, and on roots of underground storage stems such as bulbs and corms. (An herbaceous plant or herb is nonwoody and can die to the ground in freezing climates.)

Symbiotic Relationships in Roots

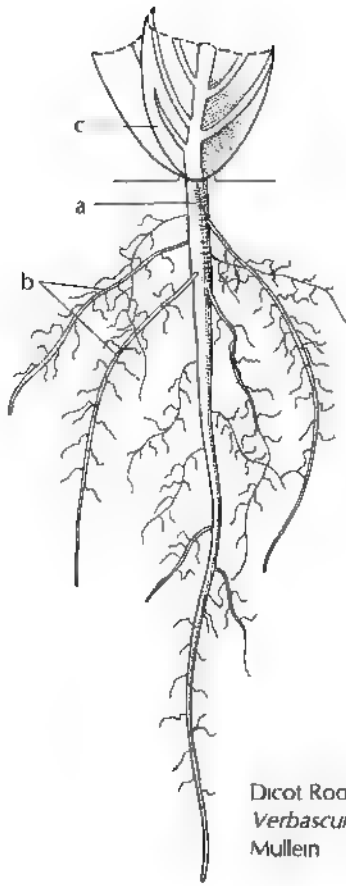
Nodules Involved in Nitrogen Fixation. Some plants are stimulated by certain genera of bacteria to develop extra tissues in the roots in the form of nodules (l), where nitrogen (N_2) in the air is “fixed,” that is, converted to other forms, mainly ammonia (NH_3), which can then be converted to organic forms such as amino acids. The bacteria and plant exchange nutrients and metabolites in a mutually beneficial relationship. Examples are found in alfalfa (*Medicago*), clover (*Trifolium*), garden pea (*Pisum sativum*), and garden bean (*Phaseolus vulgaris*).

Mycorrhizae. These are mutually beneficial associations between fungi (n) and plant roots (o). For the plant, the fungi increase the uptake of minerals, particularly phosphorus, and also water. For the mycorrhizal fungus, the plant root cells provide sugars, amino acids, vitamins, and water. Mycorrhizae are classified according to whether the fungal strands (hyphae) invade (endomycorrhizae) or surround (ectomycorrhizae) the root cortical cells. A third class is where fungi both invade and surround (ectendomycorrhizae) root cortical cells. Most plants have mycorrhizal associations, which help them compete with other plants. Mycorrhizae develop best in nutrient-poor soils.

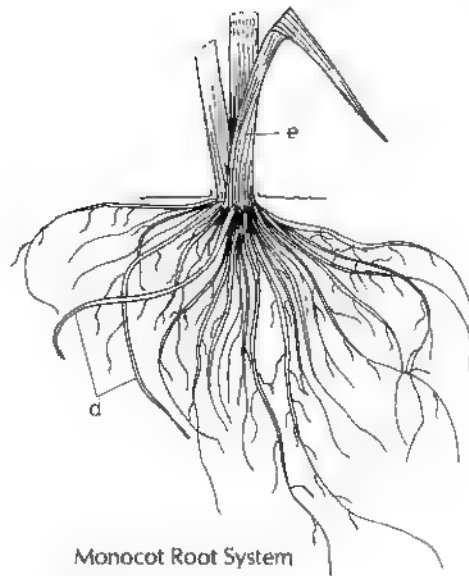
COLOR CODE

tan: dicot root system (a, b), scale leaves (j), stem axis (k), nodules (l)
green: leaves (c, e, g), prop roots (h)
white: monocot root system (d), roots (i, m, o), roots swollen with mycorrhizal fungal strands (n)
orange: storage tap root (f)

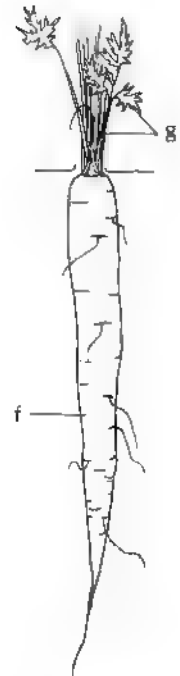
Root Types and Modifications



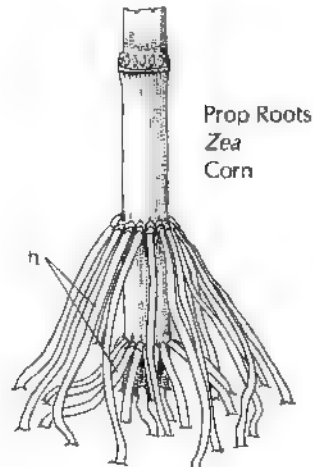
Dicot Root System
Verbascum
Mullein



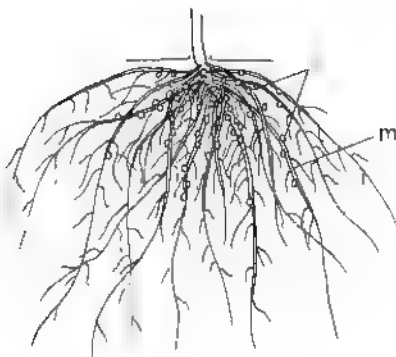
Monocot Root System
Oryza
Rice



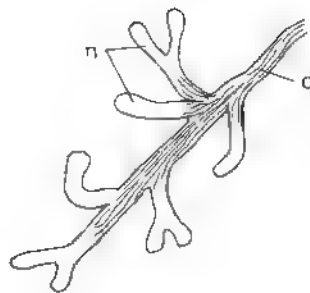
Storage Tap Root
Daucus
Carrot



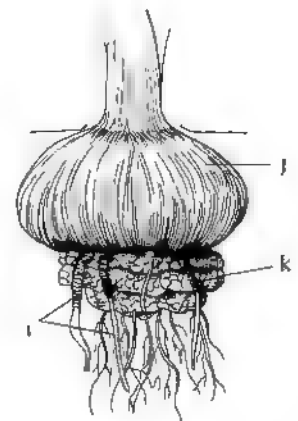
Prop Roots
Zea
Corn



Dicot Roots with Nodules
Phaseolus
Bean



Conifer Roots with Mycorrhizae
Picea
Spruce



Contractile Roots
Gladiolus corm

Root Tissues

Basic Differentiation Regions of the Root

Apical Meristem. The root apical meristem (a) is located at root tips. It produces new root cap (b) cells below, and above, it produces cells that contribute to protoderm (c), ground meristem of the cortex (d), and procambium (e), the three primary meristems that initiate tissues.

Root Cap. The function of the root cap (b) is to protect the apical meristem and to aid the developing root as it penetrates the soil as the root elongates. It is composed of parenchyma cells whose walls, along the surfaces of the root cap, are mucilaginous to provide easier passage through soil particles. As cells (f) are sloughed off, more cells are produced by the apical meristem.

Elongation Region. Back of the apical meristem is the region (g) where most elongation of the root takes place.

Mature Root. In primary growth, the epidermal cell walls of the mature root (j) become cutinized or suberized with wax-like substances. With secondary growth, the cork cambium replaces epidermis (k) and cortex with root bark tissues, cork and phelloderm.

Non-vascular Tissue Systems

Epidermis. The epidermis is the outermost tissue of the root. It is usually a single layer. In the root elongation zone are root hairs (h), lateral protrusions of epidermal cells (i), which are active in water and mineral nutrient uptake.

Cortex. Basically, cortex tissue is made up of parenchyma cells. In conifers and dicots with secondary growth, the cortex (d) is shed. Monocots, without secondary growth, retain their cortex and many develop sclerenchyma tissue. Food, mostly as starch, is stored in the cortical cells in amyloplasts (see 3). Proplastids may develop into chloroplasts in cortical cells if the root is exposed to light.

Endodermis. The innermost layer of cortex (d) that encircles the vascular tissue is called the endodermis (l).

Along the radial and transverse walls of endodermal cells is a suberin-rich fatty layer called the **casparian strip** (m). It blocks absorbed soil water from passing between the cells to the xylem; thus, water and mineral nutrients must pass through the selectively permeable membranes of endodermis cells instead, an effective filtering system (see 17).

Vascular Tissue System

Pericycle. The central cylinder (n) of vascular tissue is surrounded by thin-walled parenchyma tissue called pericycle (o). The pericycle is the site where vascular cambium and lateral roots originate. As a lateral root (p) penetrates through the cortex, its apical meristem and its derivative tissue systems become organized. Adventitious roots, which develop from stems, are initiated in parenchyma near differentiating vascular tissue.

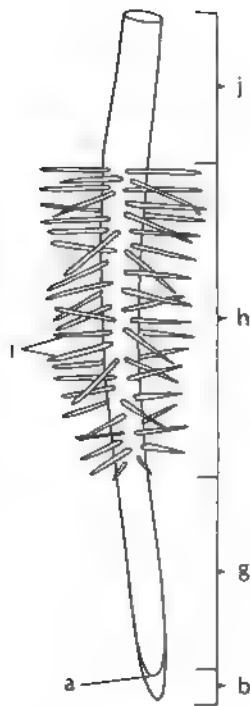
Xylem. If no xylem is formed in the center of the root, parenchyma tissue develops there. Primary xylem arms (q) radiate from the center and vary in number. The dicot types include diarch (2 arms), triarch (3 arms), or tetrarch (4 arms, q), and the monocot type is polyarch (many arms).

Phloem. Procambium cells (e), between the radiating arms of primary xylem, produce primary phloem (r) outward and xylem tissue inward. In secondary growth, the vascular cambium (s), which originates from the pericycle, extends completely around the tips of the xylem arms and inside the primary phloem poles. It produces secondary xylem (t) inward and secondary phloem (u) outward. (For a further stage in secondary growth, see 9, root cross-section.) (Lateral root adapted with permission: Esau, K., *Plant Anatomy*, 1967, John Wiley & Sons.)

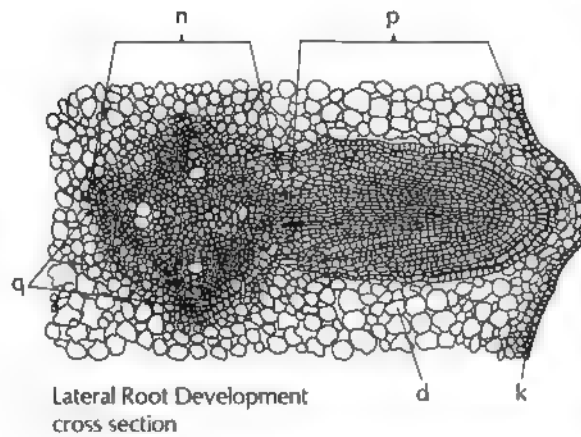
COLOR CODE

red:	apical meristem (a), procambium (e), vascular cambium (s)
colorless:	root cap (b), protoderm (c), root regions (g, h, i, j), cortex (d), cells (f), epidermis (k), lateral root (p)
tan:	endodermis (l), casparian strip (m)
yellow:	pericycle (o)
blue:	central cylinder (n), primary xylem (q)
light blue:	secondary xylem (t)
orange:	phloem (r)
light orange:	secondary phloem (u)

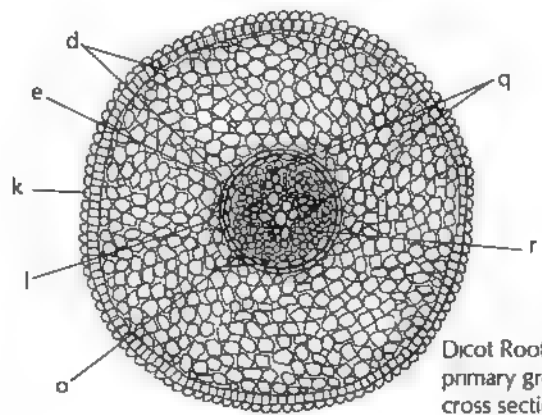
Root Tissues



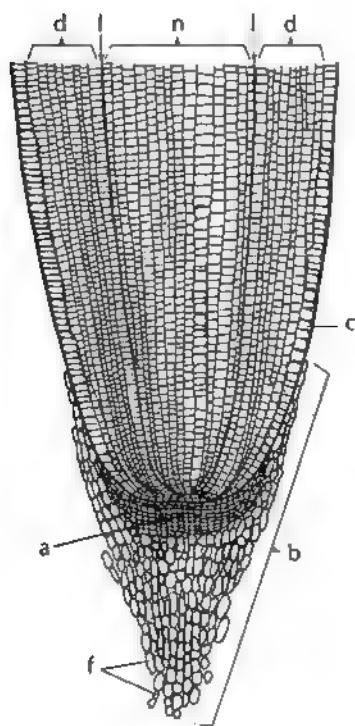
Root Regions



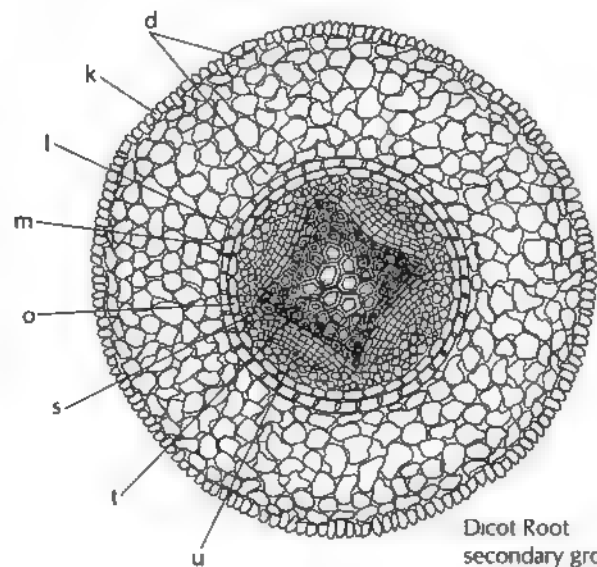
Lateral Root Development
cross section



Dicot Root (tetrach)
primary growth
cross section



Root Tip
vertical section



Dicot Root
secondary growth
cross section

Stem Structure

Functions of the stem include: photosynthesis; long-distance transport of hormones and organic metabolites in the phloem; transport of water and mineral nutrients in the xylem; support of the shoot system; sites for responses of shoot to gravity (**gravitropism**) and unilateral light (**phototropism**); food storage; and sites of initiation of adventitious roots, new leaves and inflorescences (flowers).

Parts of a Stem

Shoot Tip. The stem shoot apex produces leaf primordia (a) that develop into leaves (b).

Node. The site where a leaf or leaves, as well as axillary buds, arise on the stem is termed a **node** (c).

Internode. The elongated portion of a stem between two nodes is called an **internode** (d).

Bud. A **terminal bud** (e), which develops at the apical end of the stem, encloses a meristematic stem axis (f) with its apical meristem (g). **Axillary buds** (h) are lateral buds that form at the leaf-stem axils (nodes) and may develop into lateral vegetative shoots or flowers.

Bud Scales. Small, modified leaves or stipules that cover and protect the bud are called **bud scales** (i). Some buds lack scale coverings and are called naked buds.

Bud Scale Scar. Perennial woody stems exhibit scars (j) at the sites where terminal bud scales were shed during previous years (k, l).

Leaf Scar. A scar remains on the stem where a leaf stalk (petiole) was attached. Leaf scars (m) and buds are species-specific, and therefore, are useful for winter plant identification.

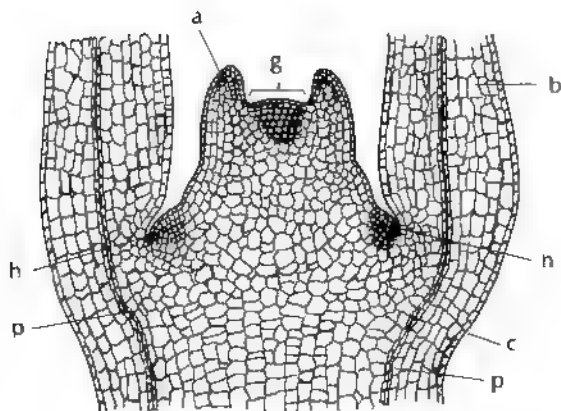
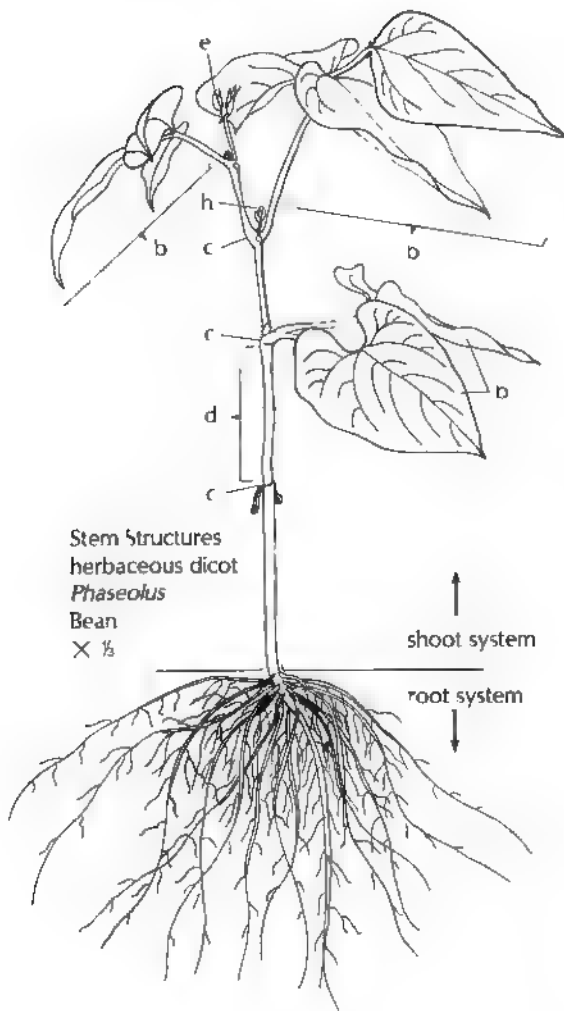
Bundle Scar (Leaf Trace). The vascular bundles (n) from a shed leaf appear as dots within a leaf scar.

Lenticel. Openings for gas and water exchange in the stem surface, called **lenticels** (o), are found on some plants with secondary growth. Lenticels are very prominent, for example on cherry (*Prunus*) tree bark.

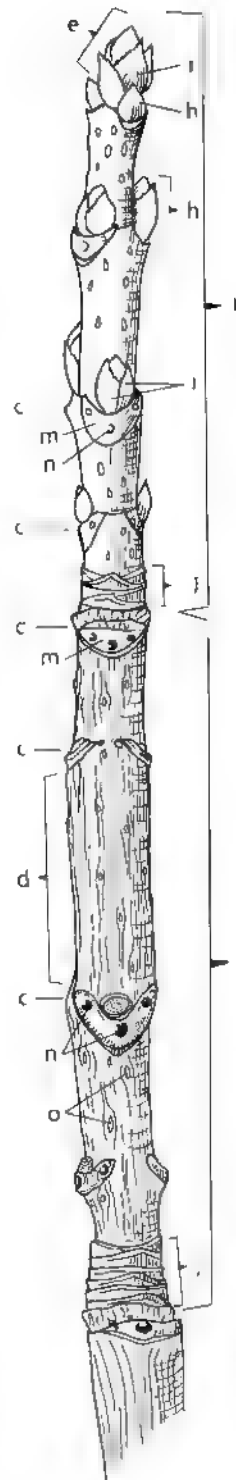
COLOR CODE

red:	apical meristem (g), maple bud scales (i), procambium (p)
green:	leaf primordia (a), leaf (b), node (c), stem internode (d), bean terminal bud (e), bean axillary bud (h)
white:	stem axis (f)
tan:	lilac bud scales (i), leaf scar (m)
dark brown:	bud scale scars (j), bundle scars (n), lenticels (o)
gray-pink:	stem growth, last year (k)
gray:	stem growth, 2 years ago (l)

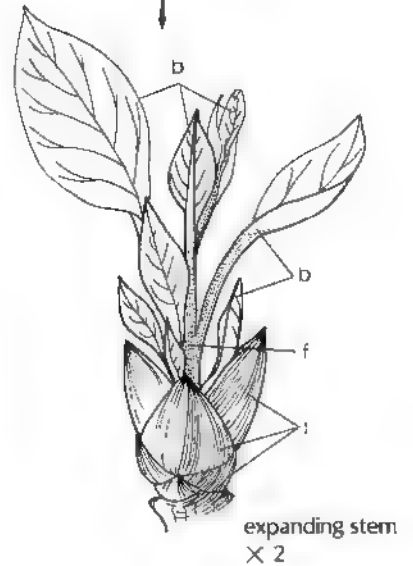
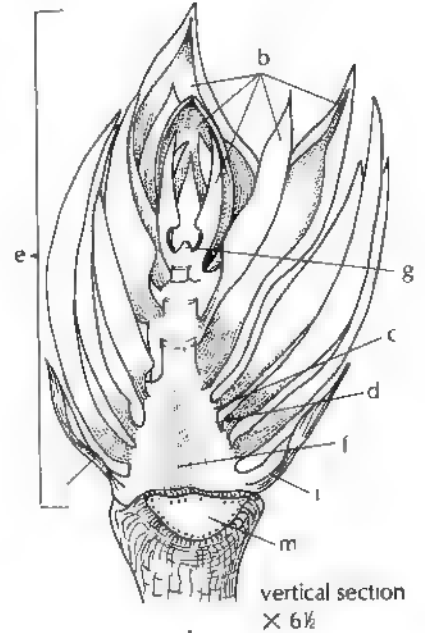
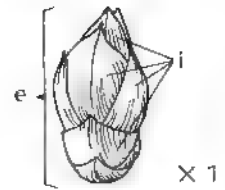
Stem Structures



Terminal Shoot Apex
enlarged, median longitudinal section



Stem Structures
woody dicot
Acer saccharinum
Silver Maple
X 3



Terminal Bud Structures
woody dicot
Syringa
Lilac

Stem Tissues

Meristems

In the primary state of stem growth, the **apical meristem** at the shoot apex produces cells that differentiate into the three primary meristems. They are the **ground meristem**, which gives rise to pith, cortex of the stem and the mesophyll of leaves, the **procambium**, which produces primary xylem and phloem of the vascular system, and **protoderm**, which produces the epidermal system. In plants with secondary growth, the protoderm is replaced by the **vascular cambium**. An **intercalary meristem** (a) is temporary, located between tissues that already have differentiated. Examples include internodes of grasses and *Equisetum*; leaves of conifers and *Welwitschia* (see 74); fruiting stalks of peanut; and stipes of kelps (see 60).

Ground Tissue System

Dicot and Conifer Stems The ground tissue between vascular tissue (d) and epidermis (e) is **cortex** (f). It consists of parenchyma tissue with intercellular spaces, but may include sclerenchyma and collenchyma tissues. If the vascular tissue forms a ring between the cortex and the center of the stem, in the center is pith (g). In conifers, the cortex (f) may have resin ducts (h).

Monocot Stem. With usually dispersed vascular bundles (i) in the ground tissue, the parenchyma (j) is not differentiated into pith or cortex.

Vascular Tissue System

Dicot and Conifer Stems. Vascular bundles (d) are arranged in a ring around the stem. In primary growth, all cells of the procambium differentiate into primary vascular tissue (k, l). In plants with secondary growth, some of the meristematic cells remain and usually form a contiguous ring of vascular cambium (m), which begins to produce secondary phloem (n) outside, and secondary xylem (o) inside. The yearly additions of secondary xylem are commonly called "growth rings." The ages of trees are determined by the number of growth rings in the trunk near the base of the tree trunk. Rings can be counted visually or by use of an increment borer.

The cambium forms two systems of vascular tissue, one vertically up the axis, and the other horizontally across the axis (called a ray system). Inward from the cambium, xylem rays (p) are produced, and outwardly phloem rays (q) are produced. Associated with the rays

are gum ducts in dicots, which contain resins, oil, gums, and mucilages. Comparable to **gum ducts**, some conifers have **resin ducts**. Secondary xylem tissue, "wood," may be composed of sapwood (r) and heartwood (s). Sapwood consists of live xylem components, active in the transport of water and mineral nutrients. The inner heartwood is composed of inactive xylem that stores secondary metabolites. Organic compounds such as oils, gums, resins, and tannins fill the cells that prevent wood rot caused by fungi and other organisms.

Monocot Stem. Monocots have no vascular or cork cambia and, therefore, no secondary growth. They exist in a primary state of growth (herbaceous plants). In large plant bodies such as palms, a thickening of the trunk occurs by multiple divisions of parenchyma cells of the procambium. In some members of the lily family (Liliaceae) such as *Yucca* and *Dracaena*, divisions outside the vascular bundles account for thickening of the stem axis.

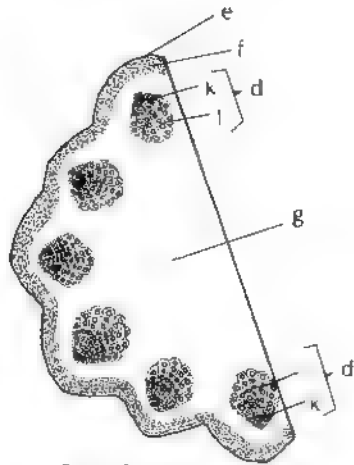
Secondary Dermal Tissue

In woody dicots and conifers, the epidermis is replaced by periderm (t), "outer bark." The **periderm** is composed of **cork cambium** (phellogen, u), **cork** (phellum, v) and **phelloderm** (w). The cork cambium (u) produces phellem (v) toward the outside and phelloderm (w) toward the inside of the periderm. Cork cells at maturity are dead, and most are filled with suberin. The cork covering of stem surfaces functions for protection. It is compressible and water- and oil-resistant, and protects against insect and fungal attacks, cold, and, in some trees (e.g. redwood and sequoia), fire. Openings in the cork tissue, **lenticels** (x), serve the same function as stomata in gas exchange. Secondary phloem (n) and periderm (t) together are commonly called "bark."

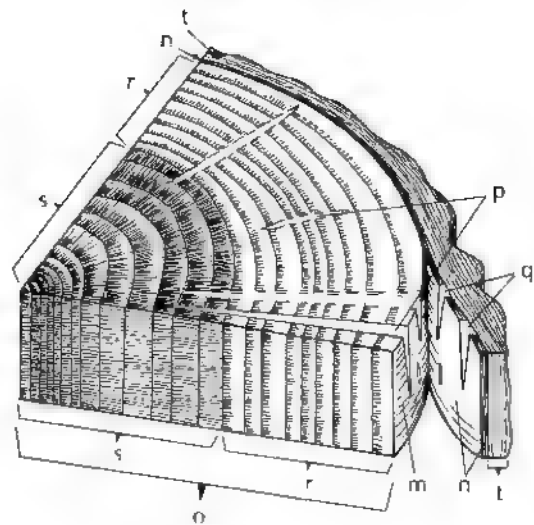
COLOR CODE

red:	intercalary meristem (a), vascular cambium (m), cork cambium (u)
green:	ridge (b), grooves (c), cortex (f), parenchyma (j)
colorless:	epidermis (e)
yellow:	resin ducts (h)
orange:	primary phloem (k)
blue:	primary xylem (l)
light orange:	secondary phloem(n), phloem rays (q)
light blue:	secondary xylem (o,r,s) xylem rays (p)
tan:	pith (g), periderm (t), cork (v, x), phelloderm (w)

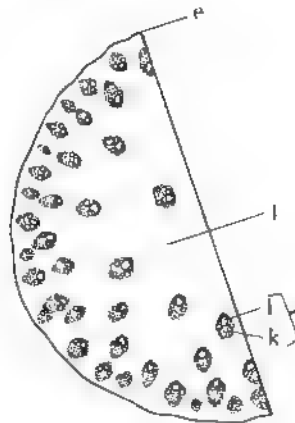
Stem Tissues



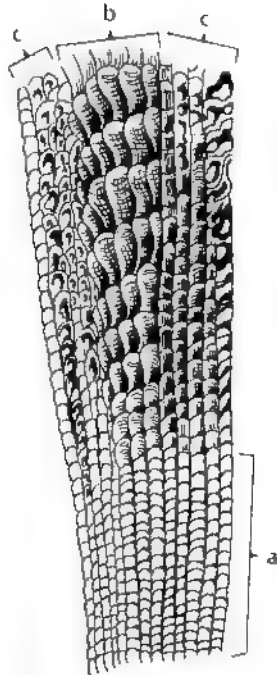
Dicot Stem, $\frac{1}{2}$ primary growth cross section



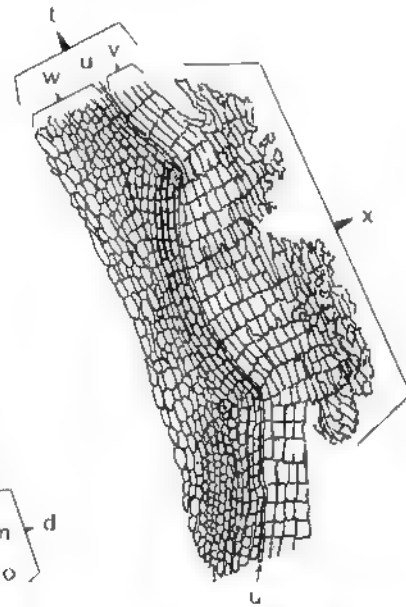
Dicot Stem, $\frac{1}{4}$ secondary growth cross section



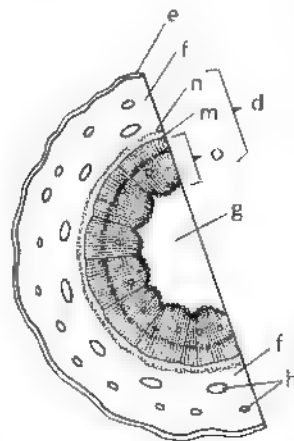
Monocot Stem, $\frac{1}{2}$ primary growth cross section



Equisetum Stem Internode greatly enlarged lower portion is intercalary meristem



Woody Dicot Outer Bark lenticel periderm



Conifer Stem, $\frac{1}{2}$ secondary growth cross section

Stem Modifications

Stems may be of various forms to serve different functions, such as for food or water storage, for subterranean or aerial anchoring devices, as a means of asexual reproduction, or for climbing.

Bulb. A bulb is a short, underground, food-storage stem axis with extremely reduced internodes and surrounding fleshy scale leaves (a). An onion is the example here.

Corm. A solid, bulb-like, underground stem without fleshy scales forms a corm. It has greatly shortened internodes. Examples are the food-storage, reproductive corms of *Gladiolus* and *Crocus* (shown).

Pseudobulb. Many orchids grow on branches or trunks of other plants (**epiphytes**). These plants develop a fleshy stem internode with water storage parenchyma. Other orchids, in contrast, are **terrestrial** (grow in the soil.)

Rhizome. Found near or below the soil surface, a **rhizome** is an underground stem that produces scale-like leaves and adventitious roots at the nodes. Rhizomes are in *Iris* (see 129), *Equisetum* (see 20, 66), and Irish potato. A potato rhizome with a developing, edible tuber is shown.

Spur Shoot. Some trees have short, woody stems with shortened internodes, such as apple (see 99) and *Ginkgo* (see 72). In apple, the spur shoots produce flowers and fruits. In *Ginkgo*, they produce pollen-producing male strobili on male trees or fruits from female strobili on female trees (dioecious condition, see 72).

Stolon. A lateral stem, "runner" (k), from the base of a plant develops long internodes, and where the apex touches the soil, a new plant with shoots and adventitious roots forms at a node. Strawberry (see 20) and strawberry begonia (shown) form stolons.

Succulent Stem. Fleshy water storage stems of parenchyma are found in the spurge (see 103) and cactus (see 85) families. A fleshy cactus stem is shown. Other families containing representative genera with fleshy stems are found in the aster family (see 119) and geranium family (see 108).

Tuber. Tubers are swollen, underground food storage stems arising at the tips of rhizomes. They bear buds, "eyes," at the nodes on the potato tuber. These "eyes" develop into potato sprouts (shoots) when the potato starts to grow.

Vine. Vines are stems with long internodes and may have one of various types of climbing devices such as tendrils opposite leaves at a node as in grape (see 104), modified stipule tendrils (w) as in green brier, disc-tipped tendrils (t) as in Virginia creeper, adventitious roots as in philodendron and ivy (q), twining leaf tips as in gloriosa lily, and twining leaf petioles as in clematis, or the entire vine may twine as in wood rose (*Ipomoea tuberosa*).

Of interest... A bizarre wide flattening of the stem in some plants is called **fasciation** (not shown), caused by viruses, some bacterial pathogens, or herbicidal (2, 4-D) drift. The most familiar example is in crested cockscomb (*Celosia cristata*). The condition can occur in herbaceous and in woody plants. Flowers may crowd together in a mass at the end of the flat stem.

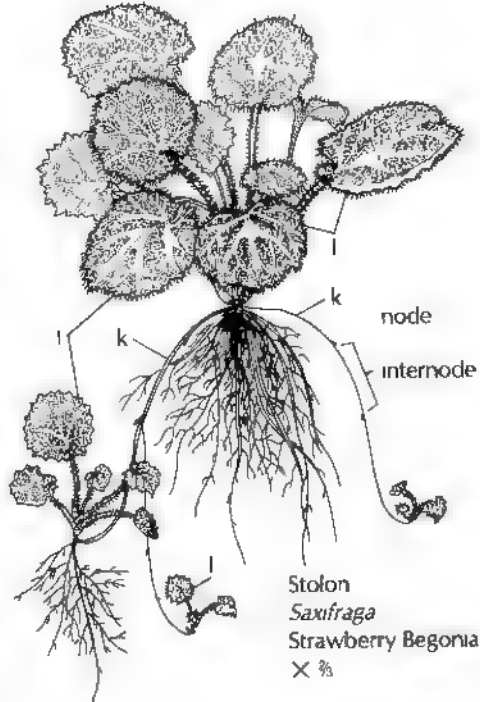
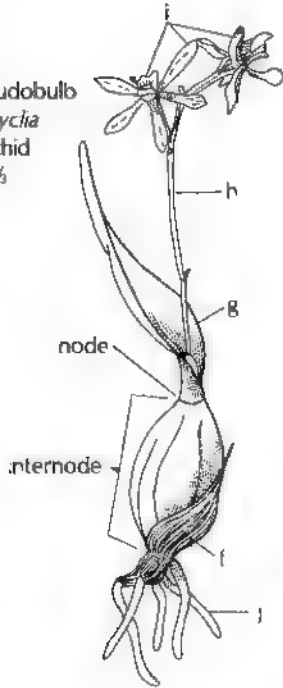
Witches'-broom is the term used to describe an abnormal bushy growth of stems that seem to originate from one point. A dense cluster of branches with no apical dominance forms. There are various causes depending on the species of herb or woody plant afflicted: insects, bacteria, viruses, or fungi.

COLOR CODE

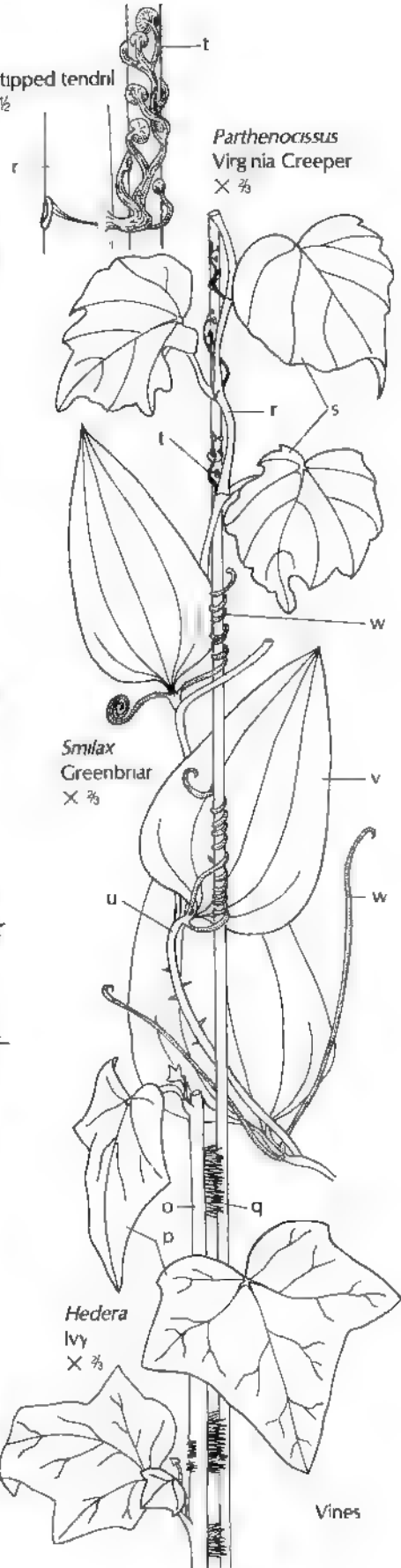
white:	fleshy scale leaves (a), leaf buds (c), roots (j, q), potato rhizome and tuber
yellow-tan:	outer scale leaves (b)
tan:	onion stem axis, bud scale (d), scale covering (e, f), stem (o, r), tendril (t)
light yellow:	corm internodes, flower petals (i)
green:	leaf (g, n, s), stem (m)
purple-green:	orchid pseudobulb (internode), stipe (h), leaf (l)
purple-red:	stolon (k)
dark green:	leaf (p)
light green:	stem (u), leaf (v), tendril (w)

Stem Modifications

Pseudobulb
Encyclia
Orchid
X ½

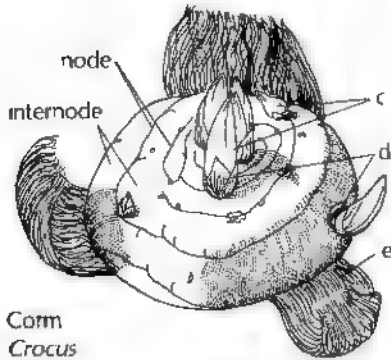


disc-tipped tendrils
X 2½



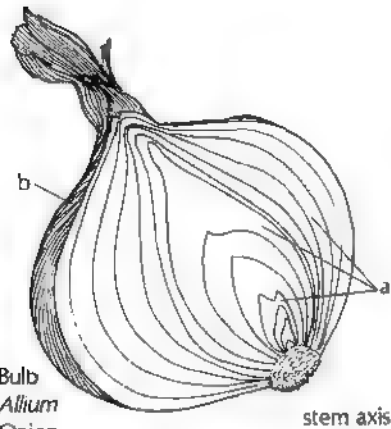
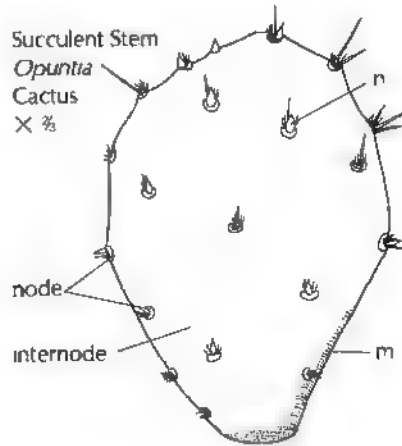
Parthenocissus
Virginia Creeper
X ½

Smilax
Greenbrier
X ½

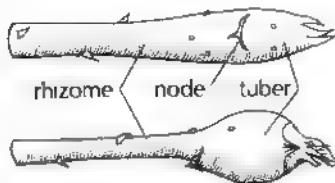


Corm
Crocus
X 1½

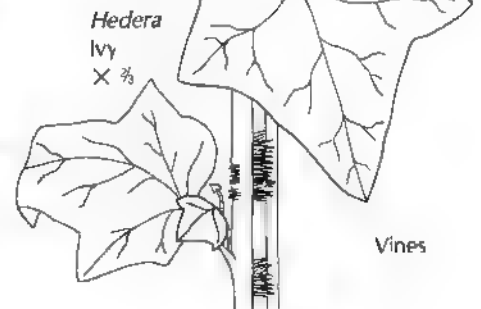
Succulent Stem
Opuntia
Cactus
X ½



Bulb
Allium
Onion
vertical section
X ½



Rhizome
with developing tuber
Solanum tuberosum
Potato
X 2



Hedera
Ivy
X ½

Stem—Water Transport

Transpirational “Pull”

Water has a natural cohesiveness, surface tension, so will rise in a tube (capillary action), but not very high. How then does water rise from the soil to the leaves of tall trees? The air surrounding mesophyll cells in leaf tissue (see 22) has a humidity of 100% and, thus, the tissue air is saturated with water. Air outside the plant usually has a lower humidity unless it is raining. The evaporation of moist air as it escapes the leaf tissue, via the pores (stomata), provides a “pull” for water movement within the plant.

Loss of water by evaporation from leaf surfaces is called **transpiration**. Water (a) moves upward in the plant from a region of higher water concentration in the soil to a region of lower water concentration, the dry air outside the leaves.

Pathway of Water Transport

Water (a) in the soil is absorbed by the epidermal root hairs (b). It then moves across the root through living cortical cells (c), is “filtered” through the semipermeable membranes of endodermal cells (d) passes through the pericycle (e), and enters the water-conducting cells (tracheids and vessel elements) of the xylem (f). Once in the xylem of the vascular system, water rises up the root to the stem and into the leaves.

The maximum rate of water rise recorded in the roots of several oak species is 60 meters per hour. From the xylem, water enters the mesophyll tissue of the leaves and evaporates into the atmosphere via epidermal stomata when they are open. Much smaller amounts of water are lost from leaf cuticle and bark lenticels in the stems.

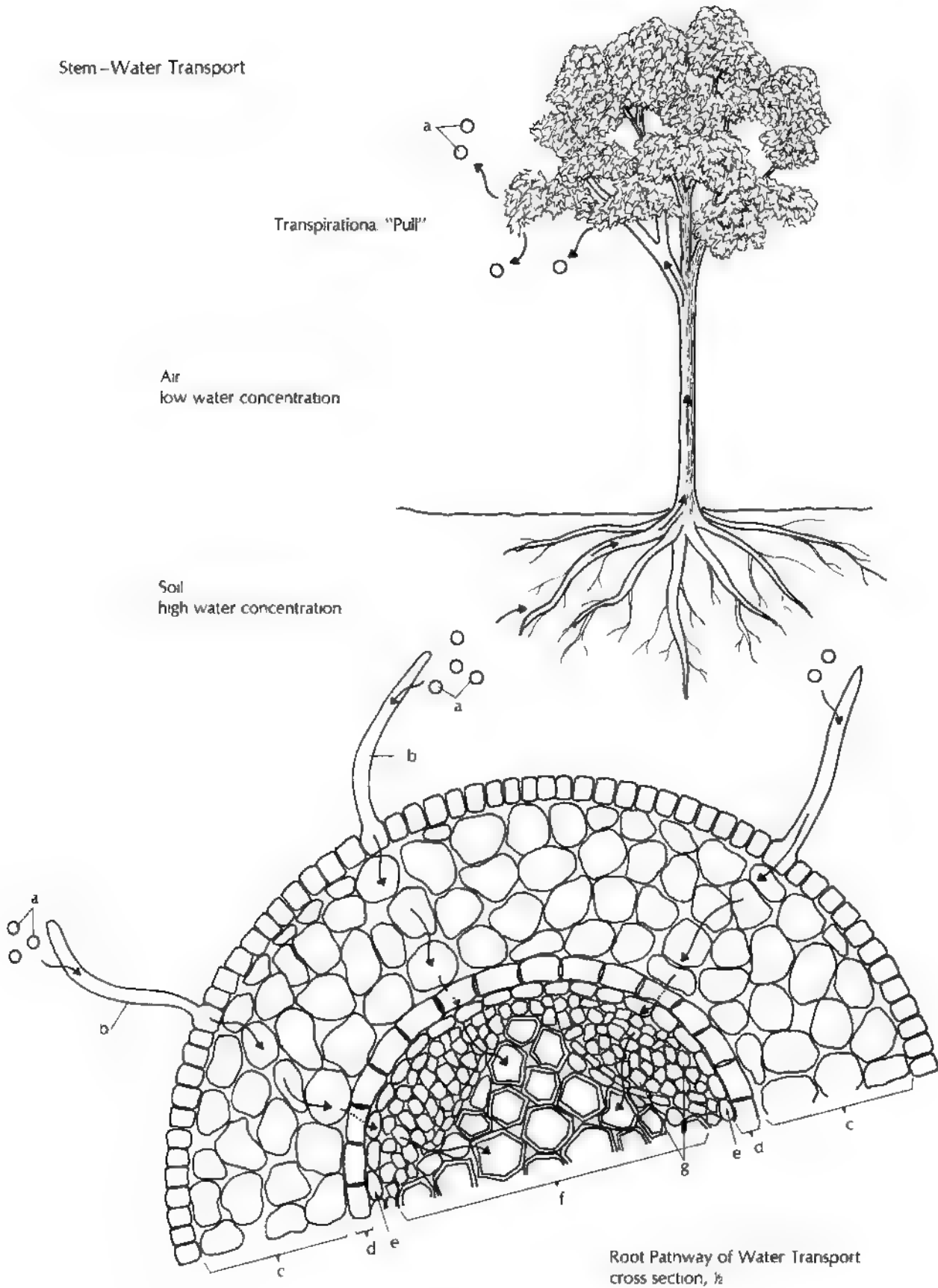
Environmental Influences

The rate of water transport in most plants is at a maximum during the daytime when air temperatures are high, relative humidity is low, and stomata are fully open. When the rate of water loss by transpiration exceeds the rate of water uptake from soil, the stomata usually close. Many succulent plants that live in the desert open their stomata only at night in order to conserve water. Thus, water transport and transpiration in these plants occur primarily at night.

COLOR CODE

blue:	arrows, water (a), xylem (f)
colorless:	root hair (b), cortex (c)
tan:	endodermis (d)
yellow:	pericycle (e)
orange:	phloem (g)

Stem-Water Transport



Stem—Food Transport

Translocation is the term used to designate transport of soluble organic materials (food) from one part of a plant to another. These organic materials are mainly sugars (from photosynthesis) and amino acids and amides (products of nitrogen metabolism). Primarily, they come from leaves, which we call sources, and are transported to areas called sinks, where they are either metabolized or stored. Metabolic sinks include young, growing shoot tips (terminal and lateral), developing flower buds, growing stems, and elongating roots. Storage sinks include tubers, tuberous roots, bulbs, corms, fruits, or stem parenchyma tissue. The transport of organic solutes occurs in the phloem of the vascular system (see 11).

At maturity, the sieve tube elements (see 8) of the phloem contain cytoplasm and cytoplasmic organelles but usually lack nuclei. Connecting strands, containing cytoplasm, pass through sieve areas on the end walls of adjacent sieve-tube elements, which provide channels for flow of organic solutes from one sieve tube element to the next.

Solute Transport in the Phloem

Münch Pressure-Flow Theory

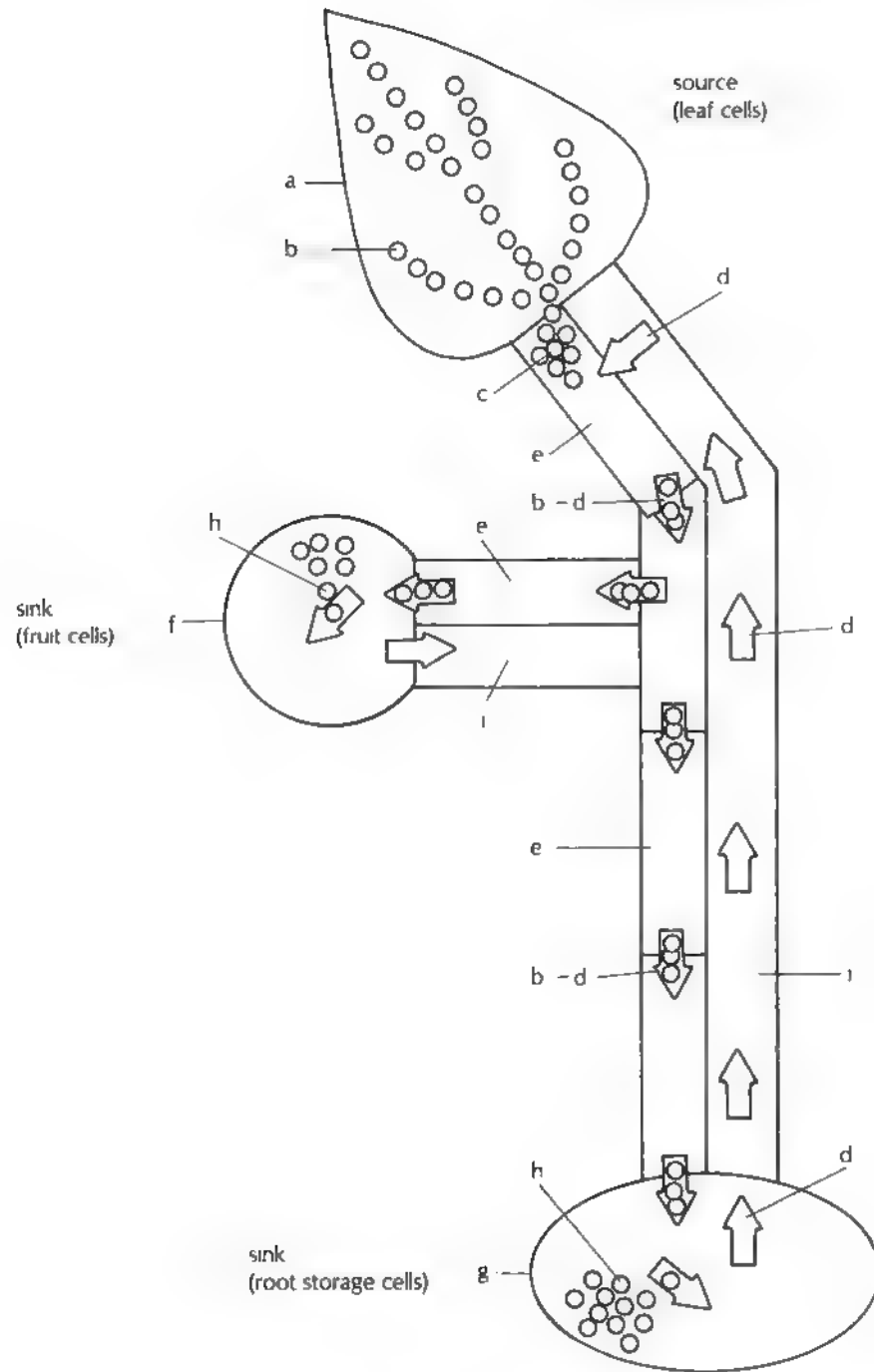
One of the most satisfactory explanations that has been proposed on long-distance transport of sugars in the phloem is the **Münch Pressure-Flow Hypothesis**. The diagram shows how it operates. Cells in the leaf (a) produce high amounts of sugar (b), which are actively (using ATP as an energy source) loaded into sieve tube elements (termed “**phloem loading**,” c) in the veins.

Because of the high concentration of sugar and low concentration of water, water (d) enters the sieve tube elements (e) from the xylem by osmosis (see 5). This causes a high water pressure, which drives the sugar “sap” (b–d) through the sieve tube elements to a sink such as a fruit (f) or a storage root (g). At the sink, the sugars are actively “unloaded” (h) into cells where they are used or stored as starch (a glucose polymer) or fructan (a fructose polymer). The high concentration of water (d) that remains diffuses back into the xylem (i).

COLOR CODE

orange: circles of sugar (b, c, h)
blue: arrows of water (d)

Stem - Food Transport



Münch Pressure-Flow System

Stem—Apical Dominance

Apical dominance is the inhibition of the growth of axillary buds by the terminal bud of a shoot. When apical dominance is lost, axillary buds start to grow. This often occurs during flowering. In plants such as oats (*Avena sativa*) and sunflower (*Helianthus annuus*, a, b) with a very strong apical dominance, axillary buds may never develop during the vegetative phase of shoot development in both species, or in sunflower even when the plant is flowering (c).

In plants such as wheat (*Triticum*) or *Coleus*, where apical dominance is weak, axillary buds may start to grow. In *Coleus*, the lowest lateral buds on the primary shoot (d) develop into lateral shoots (e) first, and those near the top (f) last.

In horticulture, “**pinching off**” the shoot tip of a dicot plant removes the terminal bud, breaking apical dominance, and results in a “bushy” plant as the axillary buds form shoots. Removing terminal buds produces thickly branched hedge plants, more flower shoots in plant such as chrysanthemums and asters and encourages more foliage growth in dicot houseplants.

In grasses, the shoots that develop from lateral buds are called **tillers** (h). Cereal grasses, such as wheat and rice (*Oryza*), that produce tiller shoots during the vegetative phase of shoot development, produce more

“heads” of flowers (inflorescences) during the reproductive phase, and hence, yield more grain (i) per plant than cereals that do not tiller until the reproductive phase is underway or after harvesting, such as oats and annual ryegrass. Even corn produces “**suckers**” (tiller shoots), which are often removed to enhance yield in “ears” of the main shoot.

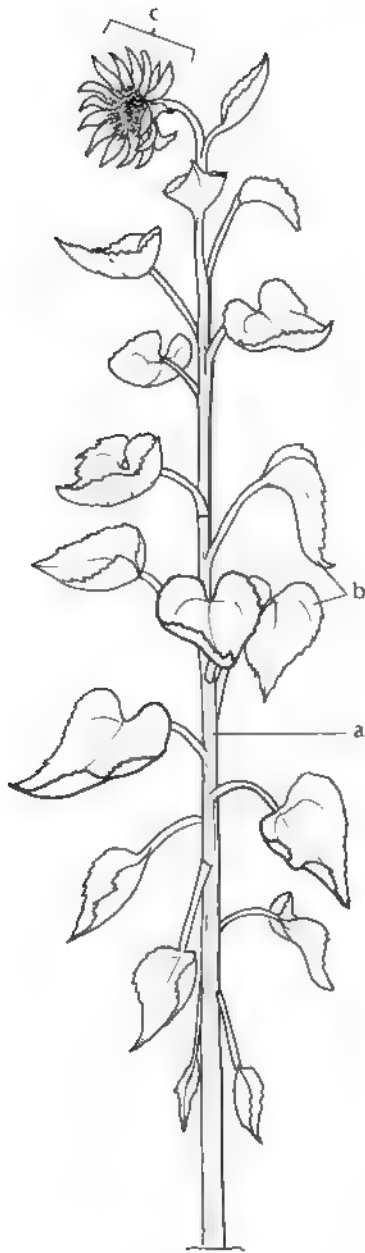
Apical dominance is regulated by two growth hormones: auxin (IAA, indole-3-acetic acid) from the terminal bud (k) and **cytokinin** (e.g., zeatin) from the roots. When the ratio of auxin to cytokinin decreases in favor of more cytokinins, apical dominance is lost and axillary buds are released to expand.

To demonstrate how auxin is involved, three alike plants with strong apical dominance can be used. One plant is used as a standard of comparison, the control. In another plant, the terminal bud is removed and lanolin paste (l) is applied to the cut surface. For the third plant, the apical bud is also removed and lanolin paste containing 0.1% auxin (m) is applied. After a period of time, the results show that in the control plant and the plant with the auxin application, the axillary buds (n) have remained suppressed. But in the plant without terminal bud or auxin application (lanolin only), apical dominance has been lost; the axillary buds are released and develop into elongated shoots (o).

COLOR CODE

dark green:	shoot (a), leaves (b)
yellow:	flower (c), lanolin (l)
purple:	shoots (d, e, f), leaves (g)
green:	tiller (h), leaves (j), terminal bud (k) lateral buds (n), lateral shoots (o)
tan:	grain (i)
orange:	lanolin with auxin (m)

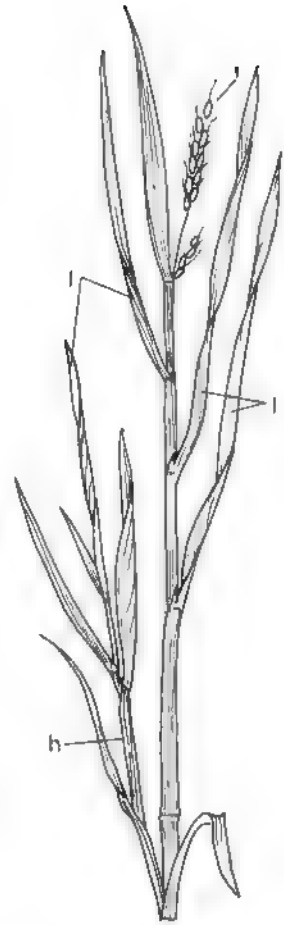
Stem - Apical Dominance



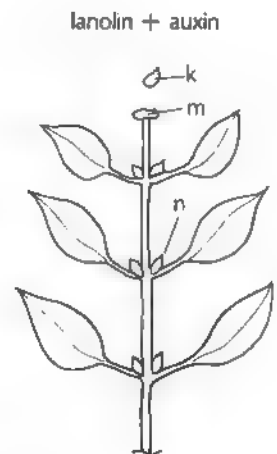
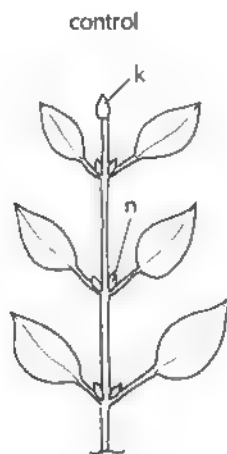
Strong Apical Dominance
Helianthus
Sunflower
X 1/2



Weak Apical Dominance
Coleus blumei
Coleus



Weak Apical Dominance
Oryza sativa
Rice



Apical Dominance Experiment Results

Stem—Growth Movements

A **tropism** is growth in response to an environmental stimulus. Growth in response to unequal light intensities is called **phototropism**, while growth stimulation by gravity is called **gravitropism**. When movement is toward the source of stimulation, it is positive, and when away from the stimulation source, it is a negative response.

Phototropic Responses

Positive Phototropism. Shoots exhibit positive phototropism by growing towards light. When a dark-grown oat seedling (a) is exposed to a light source from the right, the shoot curves to the right (b) by cell elongation on the dark side. It was discovered that a transmissible substance must be produced by the tip of the outermost seedling leaf, the coleoptile (c).

If a piece of mica (d) is inserted in the tip, no curvature occurs when a seedling is placed in a light source from the right. With the coleoptile tip cut off (e), the shoot (f) does not curve toward the light. It is known that the hormone, **auxin**, is produced in the coleoptile tip. When a tip (g) is placed on an agar block (h) with a glass cover slip (i) dividing it, a greater concentration of auxin (j) arrives on the side of the block away from the light source.

Negative Phototropism. Roots (l) exhibit negative phototropism by growing toward the center of gravity. **Skototropism** is a form of negative phototropism ex-

hibited by tropical vine shoots in which initial growth is toward dark shadows cast by trees blocking light. After the vine has climbed the tree and reaches a light-exposed area, it becomes positively phototropic.

Gravitropic Responses

Orthotropism. (Ortho = straight, correct, vertical.) Shoots (m) not only curve toward light (positively phototropic) but straight away from the earth's center of gravity (negatively gravitropic). Roots (n) and some fruit stalks show positive gravitropism by growing vertically toward the center of gravity. The root cap perceives the stimulus for the positive response, and auxin and other hormones regulate this growth process in the root.

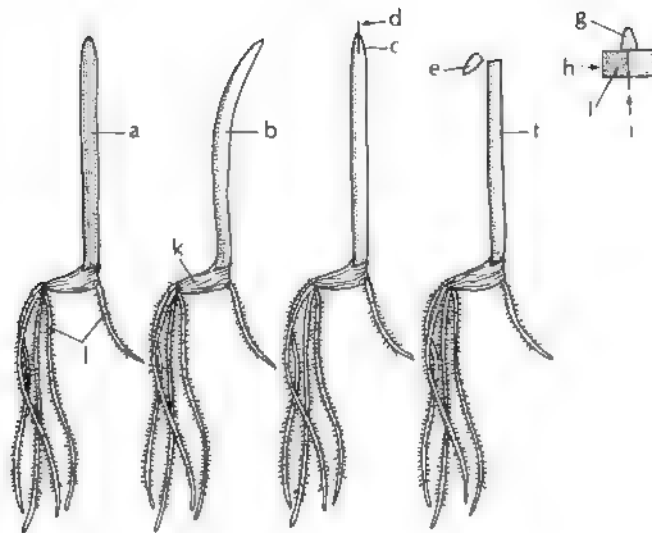
Plagiotropism. Plant parts that grow at an oblique angle from the vertical exhibit plagiotropism. Examples are lateral roots (p) and stems (q) that diverge from the main vertical axis.

Diagravitropism. When plant parts grow at right angles to the line of gravity, they exhibit diagravitropism. Rooted rhizomes (s), stolons (v), horizontal branches, and horizontal leaf orientation are some examples.

Agravitropism. Some plant parts are neutral to gravity and grow in various directions, such as the aerial roots of epiphytes (plants that grow upon other plants) and the flowering shoots of some plants that orient themselves in response to stimuli other than gravity.

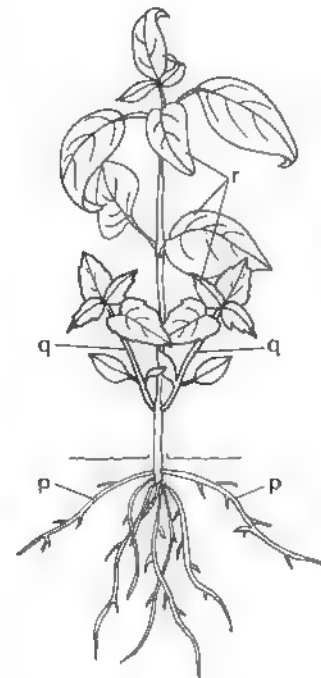
COLOR CODE

white: shoots (a, b, e, f, g, m), roots (l, n, p), flower (y)
tan: agar (h), seed coat (k), rhizome (s), shoot (t)
green: leaf cutting (o), stem (q), leaves (r, w), shoots (u), stolon (v)
red: strawberry fruit (x)

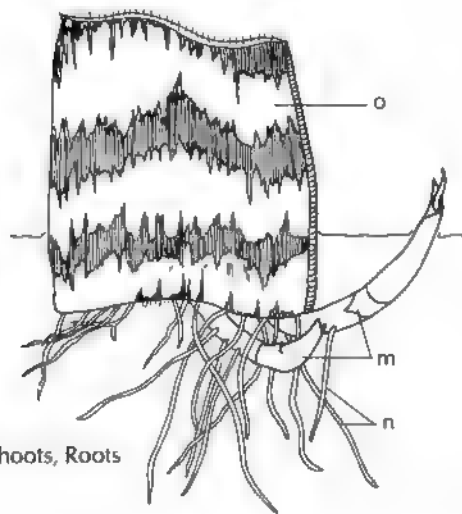


Phototropic Responses of Seedlings
Avena
Oat

Stem - Growth Movements
← light source

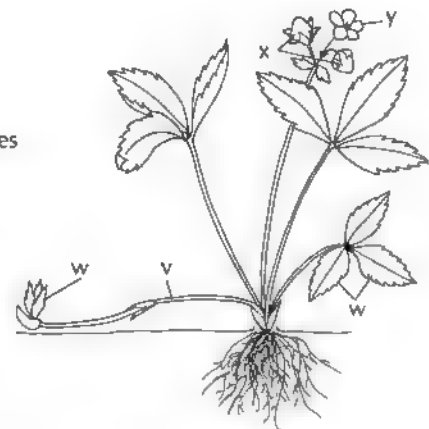


Plagiotropism of Lateral Shoots
Fuchsia

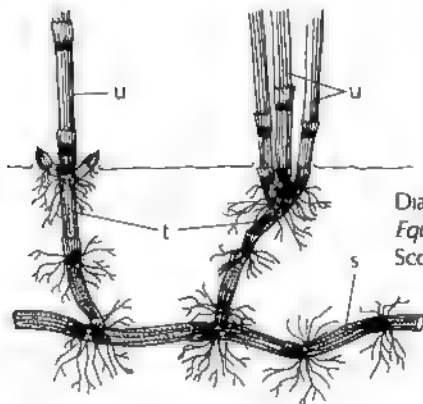


Orthotropism of Shoots, Roots
Sansevieria
Bowstring-hemp

Gravitropic Responses



Diagravitropism of Stolon
Fragaria
Strawberry



Diagravitropism of Rhizome
Equisetum
Scouring Rush

Leaf Types and Arrangement

Persistence

Deciduous. A perennial plant is one that lives more than two years. Leaves that fall off at the end of a growing period are called deciduous. Examples are found in maples (*Acer*), birches (*Betula*), and dogwoods (*Cor-nus*).

Evergreen. Leaves that remain on a plant for more than a year are called evergreen. Pines (*Pinus*), spruces (*Picea*), rhododendrons (*Rhododendron*) are exam-ples.

Leaf Types

Conifer. The leaves of conifers are needle-like (a) as on pines or scale-like as on junipers (*Juniperus*). They are usually evergreen, although some conifers have de-ciduous leaves such as larches (*Larix*). Each conifer leaf has a single vein.

Ginkgo. This unique plant (see 72) has fan-shaped leaf blades (c) with dichotomous venation in which the veins branch into two equal or unequal lengths. The leaves are deciduous and shed within a 24-hour period.

Dicot. Most dicot blades have pinnate (feather-like) ve-nation (e) in which major veins diverge from one large mid-vein, with smaller network connections between. Some dicot blades have palmate (hand-like) venation (i) where several large veins diverge from the petiole to the margins. Some dicots have parallel venation. An example is plantain (*Plantago lanceolata*).

Monocot. Most Temperate Zone monocots have nar-row strap-shaped blades (f) with sheathing bases (g) surrounding the stem (h). With parallel venation, ma-jor veins arise at the base, remain more or less parallel, and converge at the tip with small vein interconnections.

Some monocot leaf veins converge at the leaf margins instead of the tip, such as philodendron (*Philodendron*)

and some monocots have pinnate venation with Swiss cheese plant (*Monstera*) as an example.

Leaf Attachment

Petiolate. The leaf blade is attached to the stem by a stalk called a petiole (d).

Sessile. When the leaf blade is attached directly to the stem without a petiole, it is sessile (a, f, n).

Leaf Form

Simple. A simple leaf has one blade, which may be broad (i) as in the maple leaf shown, narrow, or needle-like (a).

Compound. A compound leaf is one that has two or more blade-like leaflets such as sumac (*Rhus*, j, pin-nately compound) or clover (*Trifolium*, k, palmately com-pound) attached to a petiole (d).

Leaf Arrangement

Opposite. Two leaves (l) emerge opposite each other on a stem. The example shown is milkweed (*Ascle-pias syriaca*). Generally maples, ashes, dogwoods, and members of the honeysuckle Family (Caprifoliaceae) have opposite leaves. MAD Cap is an easy way to re-member.

Alternate. In an alternate arrangement, single leaves (m) are attached spirally along the stem. Lamb's quar-ters (*Chenopodium album*) is shown (see 88). Most genera have alternate leaves.

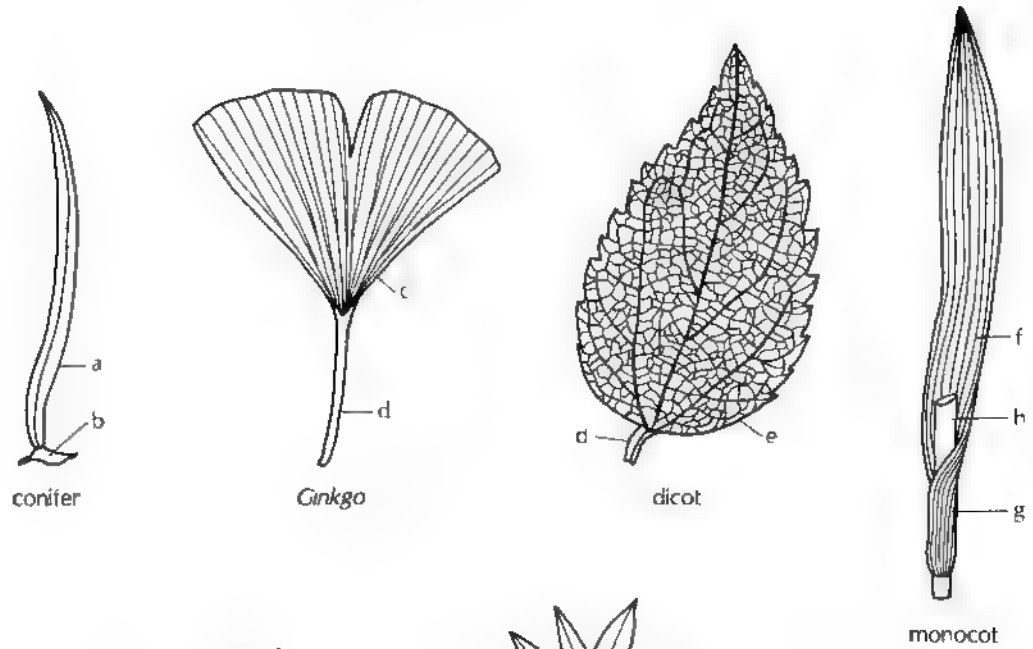
Whorled. In a whorled arrangement, several leaves (n) emerge together around a stem node. Michigan lily (*Lil-ium michiganense*) is the example shown (see 128).

COLOR CODE

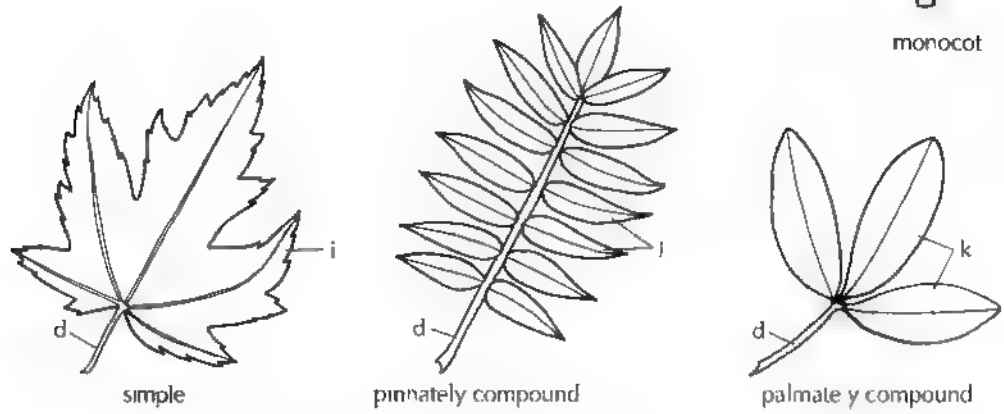
blue-green:	blade (a)
green:	shoot peg (b), petiole (d), blade (l, n)
dark green:	blade (e)
yellow:	blade (c)
light green:	blade (f, m), sheath (g), stem (h), leaflets(k)
orange:	blade (i)
red:	leaflets (j)

Leaf Types and Arrangement

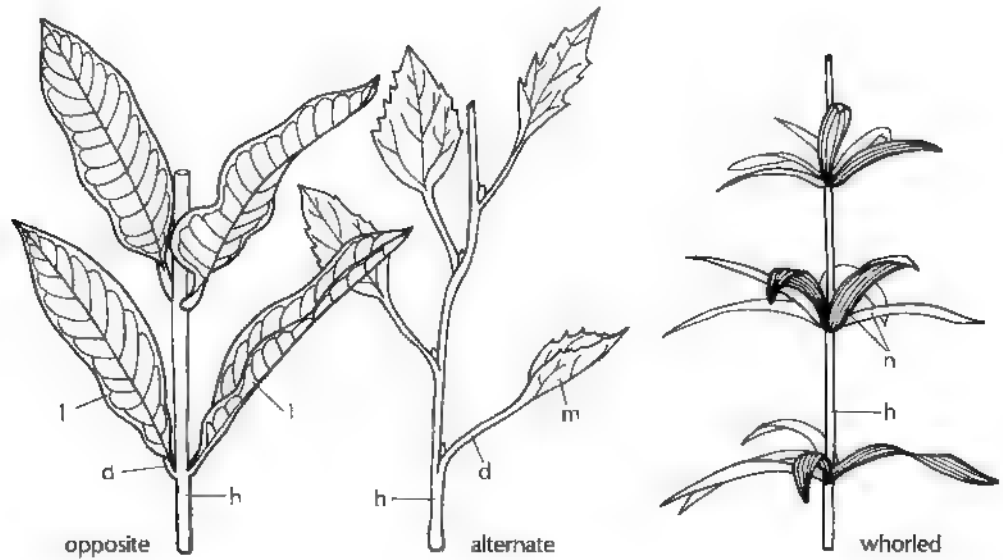
Leaf Types



Leaf Forms



Leaf Arrangement



Leaf Tissues

The leaf blade's outer surface is epidermal tissue and the ground tissue within is photosynthetic mesophyll, interspersed with "veins" (vascular bundles) of conducting (vascular) tissue. Vascular connections between blade and stem pass through the petiole.

Dicot Leaf

Epidermis. There may be one or more layers of epidermal cells (a) with cutinized outer walls that form a waterproof outer surface. Stomata of guard cells (b) are present on the upper and lower surface or only on the lower surface as shown here. Various hairs and glands may also be present (see 10).

Ground Tissue. The parenchyma cells of the ground tissue (c) are divided into palisade (d) and spongy (e) mesophyll. Usually the columnar cells (f) of the palisade layer lie under the upper leaf epidermis and contain most of the chloroplasts of the ground tissue. The spongy parenchyma (e) has irregular-shaped cells (g) with air spaces (h) between and lies above the lower leaf epidermis.

Vascular Tissue. Four small vein transections are shown which are part of the vast, interconnecting network between major veins. A leaf vein (vascular bundle) usually has xylem (i) on the upper side and phloem (j) on the lower side. The reverse may be true in major veins. A layer of parenchyma cells called a bundle sheath (k), which functions in moving materials between the vein and the mesophyll tissue, usually encloses small veins.

Monocot Leaf (Grass)

Epidermis. Along with the epidermal cells (a), guard cells (b), hairs, silica, and cork cells, grass leaves have **bulliform cells** (l). The bubble-shaped, water-filled bul-

liform cells control leaf rolling (when the leaf is dry) and unrolling (when the leaf is turgid or filled with water). Under drought conditions, bulliform cells collapse and the leaf rolls up.

Ground Tissue. In the temperate region, grass mesophyll (c) consists of only spongy parenchyma tissue whose cells contain chloroplasts—sites of photosynthesis.

Vascular Tissue. Grass leaves have bundle sheaths (k) surrounding each vein. Sclerenchyma fiber strands (m) may be associated with the veins. (Leaf transection adapted with permission: Esau, K., *Plant Anatomy*, 1967, John Wiley & Sons.)

Conifer Leaf

Epidermis. The usually small, triangular or flat "needle" leaves of conifers are adapted to dry conditions. Epidermal cells (a) have thick walls of cuticle, and sunken stomatal guard cells (b) overlapped on the surface by subsidiary cells (n). Stomata may be on one or all sides of the leaf surface. Under the epidermis may be a layer of thick-walled sclerenchyma cells called **hypodermis** (o).

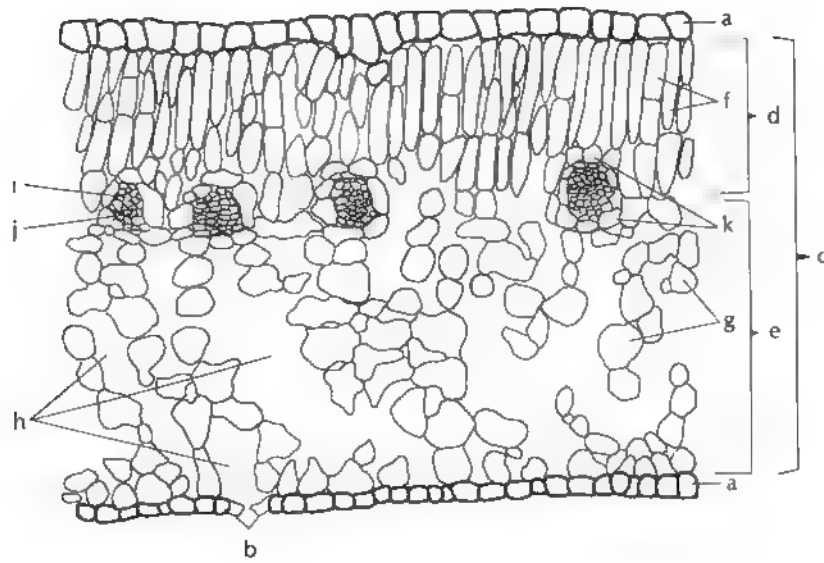
Ground Tissue. Mesophyll tissue (c) is not usually differentiated into palisade and spongy layers. Resin ducts (p) are present.

Vascular Tissue. There are one or two veins in the center surrounded by transfusion tissue (q) and endodermis (r) containing tannins and resins.

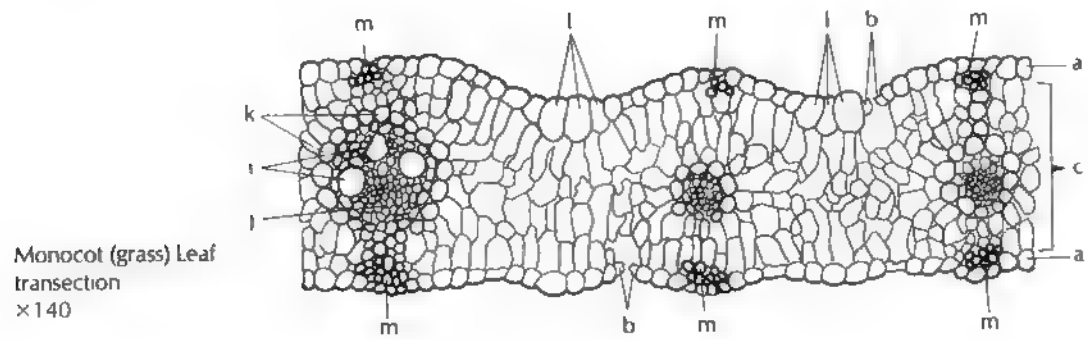
COLOR CODE

colorless:	epidermal cells (a), air space (h), bulliform cells (l), subsidiary cells (n), hypodermis (o), transfusion tissue (q)
green:	guard cells (b), monocot and conifer mesophyll (c) palisade parenchyma cells (f)
light green:	spongy parenchyma cells (g), bundle sheath (k)
blue:	xylem (i)
orange:	phloem (j)
tan:	sclerenchyma fibers (m), endodermis (r)
yellow:	resin duct (p)

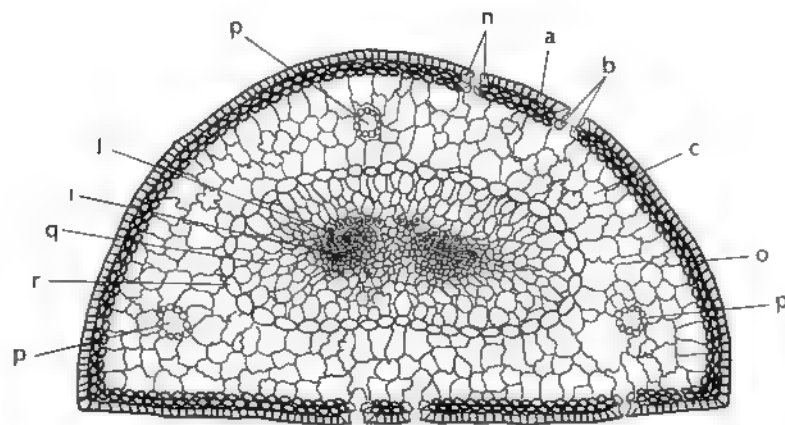
Leaf Tissues



Dicot Leaf
transection
× 280



Monocot (grass) Leaf
transection
× 140



Conifer Leaf
transection
× 78

Leaf Modifications

Leaves may become highly specialized in function, exhibiting bizarre forms. Only a few of the many leaf modifications are shown here.

Bract. Associated with a flower, **bracts** are reduced or modified leaves. Very small bracts are found in sedge and grass flowers (see 122, 123), while large colorful bracts (a) subtend flowers (b) such as *Bougainvillea* and poinsettia (*Euphorbia*). The **spathe** is an elaborate bract found in the arum family (see 127).

Carnivorous Leaves. Carnivorous plants live in low-nitrogen environments and enzymatically digest animals (mainly insects) in their leaves to supplement nutritional needs. The Venus'-flytrap (*Dionaea*) with a two-lobed leaf blade (c, d) has trigger hairs (e) that set off a response that brings the spine-covered leaf margins (f) together in a closing trap. The leaf has a wide petiole (g). On butterwort (*Pinguicula*, see 10) and sundew (*Drosera*) leaves (h), long, sticky-bulbed, glandular hairs (i) entrap and digest insects.

In pitcher-plants (*Sarracenia*), the hairy (j) lower surface of the leaf blade (k) is curved inward, forming a well of water and digestive enzymes. Nectar glands attract insects, while downward pointed hairs keep them in the leaf enclosure (see 91). The carnivorous leaf colors of the above examples attract flies (see 34).

A water plant, bladderwort (*Utricularia*) has bait and trigger hairs (o) surrounding the mouth (p) of a bladder

(q), a modified leaf. Movement of the hairs entices small crustaceans to investigate. By negative pressure within the bladder, victims are sucked in and digested, sealed in by a trap door at the mouth of the bladder.

Phyllode. This is a widened petiole that appears blade-like. In the acacia (*Acacia melanoxylon*) plant, some leaves consist of only petioles (**phyllodes**, r), while others develop compound leaflets (s).

Spine. Spines are highly reduced leaves or stipules found on many herbs, shrubs, and trees. Often a plant exhibits a series of forms (**homology**) from leaf (t) to spine (u).

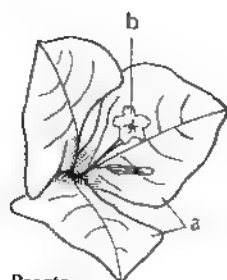
Stipule. Usually in pairs, **stipules** (v) are basal appendages to the petiole (w). They may appear as hairs, leaves, tendrils, or spines.

Succulent Leaves. An adaptation to dry environments, some plants store water in leaf mesophyll tissue. The epidermis may have thick cutinized and lignified walls to reduce water loss. In some succulents, the stomata reverse the usual condition and open only at night. The leaf epidermis (y) of living stones (*Lithops*), an example of mimicry, appears sand-colored. In the cut-away drawing, green mesophyll tissue (z) is exposed, surrounding the newly formed leaf in the center.

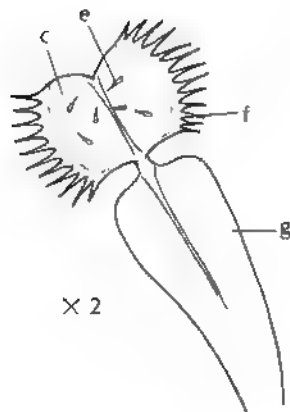
COLOR CODE

red:	bracts (a), inner blade surface (c), hairs (i, j), veins (l)
white:	flower (b), hairs (e)
yellow-green:	blade margins (f), petiole (g), blade (d)
green:	leaf (h, n), leaflets (s)
light green:	petiole (m), blade (k), leaf (t), stipule (v), mesophyll (z)
tan:	hairs (o), bladder (q), spine (u), epidermis (y)
dark green:	petiole (r, w), blade (x)

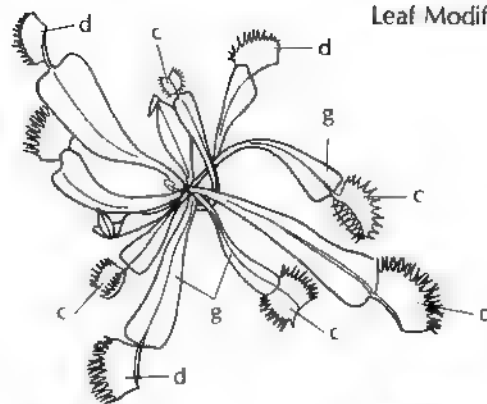
Leaf Modifications



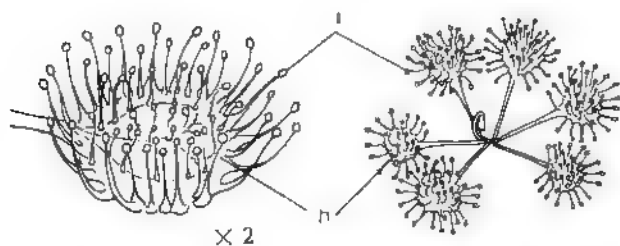
Bracts
Bougainvillea
X 1



X 2

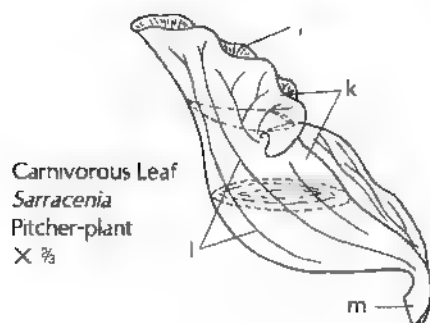


Carnivorous Leaf
Dionaea
Venus'-flytrap
X 2/3

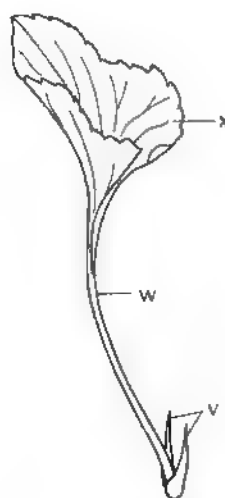


X 2

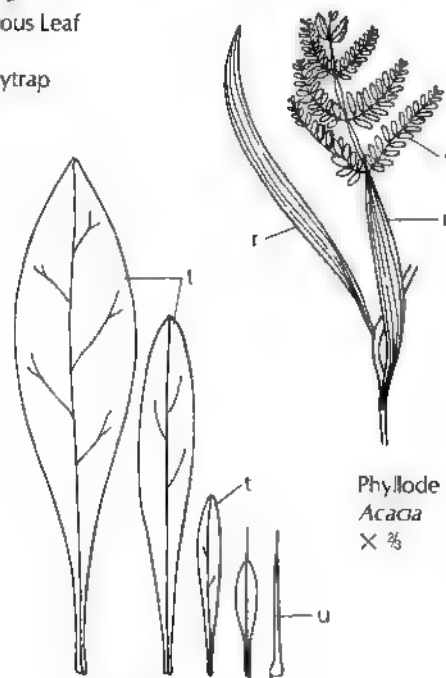
Carnivorous Leaf
Drosera
Sundew
X 2/3



Carnivorous Leaf
Sarracenia
Pitcher-plant
X 2/3

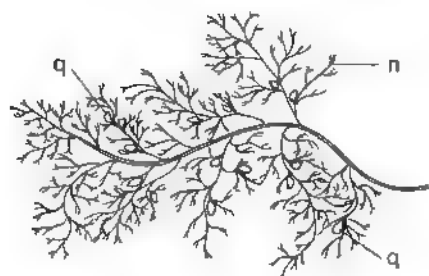


Stipule
Viola
Violet
X 1

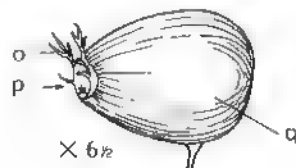


Phyllode
Acacia
X 2/3

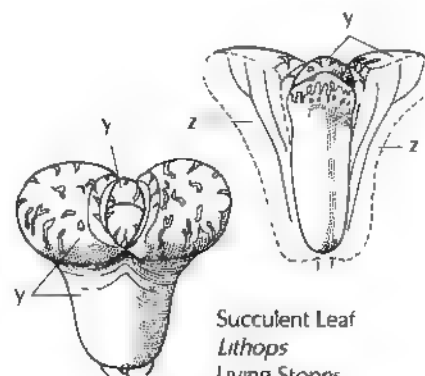
Leaf to Spine Series
Berberis
Barberry
X 1 1/2



Carnivorous Leaf
Utricularia
Bladderwort
X 2/3



X 6 1/2



Succulent Leaf
Lithops
Living Stones
X 1 1/2

Leaf—Photosynthesis

Plant Energy Source

Photosynthesis is the process in plants in which light energy is converted to useful chemical energy. In the process, carbon dioxide and water, in the presence of chlorophyll and light energy, form sugars, oxygen, chemical energy (ATP—adenosine triphosphate), and water. A general equation is shown.

With the exception of fungi, photosynthesis occurs in all major groups of organisms discussed in this book, including certain bacteria. Most plants that photosynthesize have chloroplasts, in which photosynthesis occurs. Other cells, as in photosynthetic bacteria and blue-greens, have no chloroplasts. Instead photosynthesis occurs in pigments located in the cytoplasm.

Significance of Photosynthesis

Photosynthesis is responsible for the conversion of carbon from carbon dioxide into organic compounds in plants. It allows the plant to make organic building blocks for sugars, amino acids, nucleic acids, fatty acids, new cells, starch, protein, DNA and RNA, hormones and vitamins, and many secondary compounds. Without this photosynthetic process, life would not exist on earth. Plants provide, directly or indirectly, food for all animals and all of our atmospheric oxygen. They also “fix” CO_2 in photosynthesis, which helps to reduce global warming.

Photosynthesis consists of two basic parts: a series of light reactions and a series of dark reactions. In the light reaction (a), chlorophyll a (and accessory pigments) absorb light, which “excites” the electrons in the chlorophyll molecule. The electrons are passed along through a series of carriers (acceptors), and energy (ATP) is produced, which catalyzes the dark reaction. During the light reactions, water is split, giving off oxygen.

In the dark reaction (b), carbon dioxide, products of the light reaction (reducing power), and energy are used. Carbon dioxide is “fixed” or converted into a cyclic production of a series of carbon sugars, the most important of which ultimately is sucrose, made up of 6-carbon sugars, glucose, and fructose.

C_3 and C_4 Plants

In regard to photosynthesis, plants are divided into two types: C_3 and C_4 plants. In the leaves of C_3 plants, which include most plants, light-driven carbon fixation reactions involve the formation of 3-carbon organic acids as the first stable products. In many tropical grasses C_4 photosynthesis, such as sugar cane, corn, and sorghum, the photosynthetic process is more efficient. The grass bundle sheath (see 22) produces 3-carbon acids and sugars, whereas the mesophyll tissue produces 4-carbon acids. These plants are more efficient in producing sugars because they have little or no sugar loss during **respiration** (a chemical release of energy from sugars) in the light (**photorespiration**).

The illustration shows where the photosynthetic process takes place in the leaf (c) of a C_3 plant. In the chloroplast (i), chlorophylls and accessory pigments are located in the thylakoids (j), where the light reaction takes place. Dark reactions take place in the stroma (k) of the chloroplast (see 3).

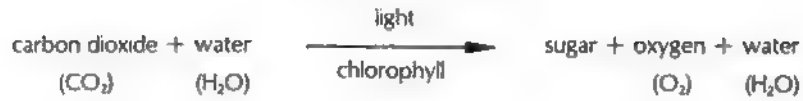
Environmental Regulation of Photosynthesis

Photosynthetic rate is regulated by the intensity of light, daylength, amounts of carbon dioxide and oxygen in the air (or water for water plants), temperature, and the level of air pollution.

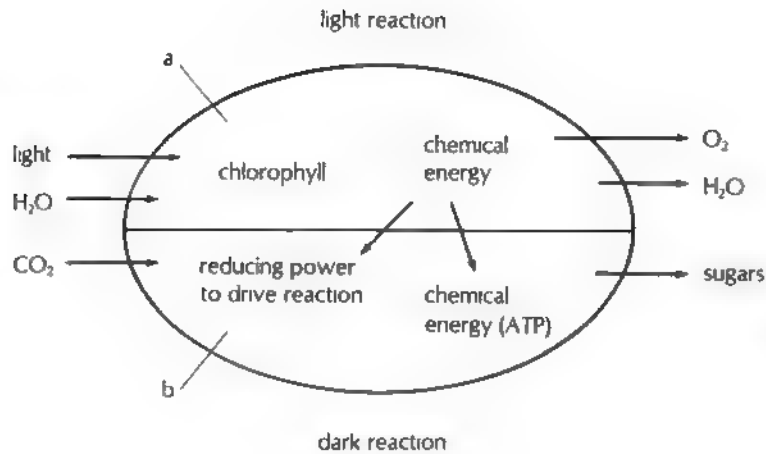
COLOR CODE

green:	light reaction (a), leaf (c), guard cells (e), palisade cells (h) with chloroplasts (i), thylakoid (j)
gray:	dark reaction (b), stroma (k)
blue:	water (xylem) in vein (d)
orange:	sugars (phloem) in vein (d)
colorless:	epidermis (f), spongy cells (g)

Leaf-Photosynthesis

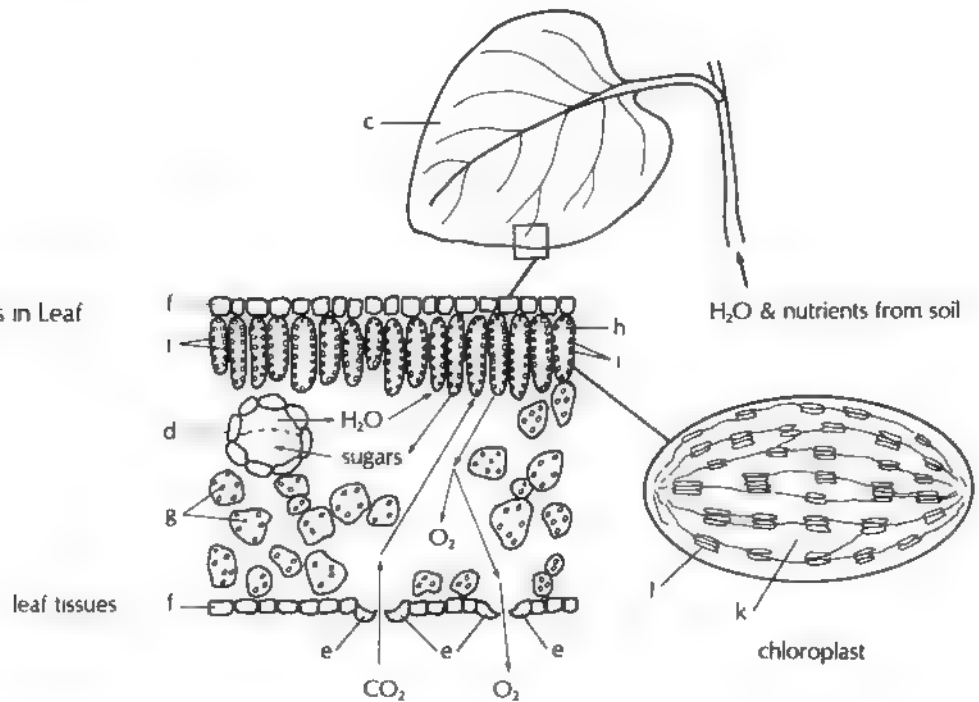


General Equation of Photosynthesis



Photosynthetic Reactions in Chloroplasts

Sites of Photosynthesis in Leaf diagram



Leaf—Nutrient Deficiency Symptoms

The essential elements that are required for the healthy growth of higher plants are carbon, hydrogen, oxygen, and those listed below. Plants take in carbon in the form of atmospheric carbon dioxide, obtain hydrogen and oxygen from water, and take up the remaining elements from the soil. By growing plants in an aqueous nutrient solution (**hydroponics**) and omitting an essential nutrient, specific deficiency symptoms can be observed.

Nitrogen. Decaying organic matter provides soil nitrogen. Also, nitrogen-fixing bacteria on some plant roots convert atmospheric nitrogen into organic forms used by plants. Nitrogen deficiency results in yellowing (**chlorosis**) of older leaves.

Phosphorus. Plants deficient in this element exhibit dark green older leaves and stunted growth. Red anthocyanin pigments sometimes accumulate.

Potassium. This element is found in wood ashes (potash). Deficiency symptoms are exhibited in older leaves that yellow and have dead (necrotic) tissue in spots, and roots are easily infected with pathogenic organisms.

Magnesium. A lack of magnesium results in a yellowing of the leaves between the veins with the tips and margins turning upward.

Sulfur. Usually, a sulfur deficiency affects the younger leaves first with the veins becoming light green and a yellowing of the tissue between them. As sulfur compounds are found in most soils, this deficiency is rare.

Calcium. Lack of calcium affects meristematic regions, resulting in the death of terminal buds and root tips.

Iron. A deficiency of iron results in a chlorosis of young leaves with the yellowing occurring between veins.

Chlorine. Without chlorine, leaves wilt, turn yellow, show dead spots, and then become a bronze color. Roots become stunted and club-shaped near the tips.

Manganese. Although a rarely found deficiency, without manganese, younger leaves form yellow speckles between the veins.

Boron. Lack of boron produces death of shoot and root apical meristems, beginning with young leaves becoming light green at the base, and root tips becoming swollen.

Zinc. A deficiency of zinc results in formation of small leaves and shortened stem internodes. The leaf margins may become distorted.

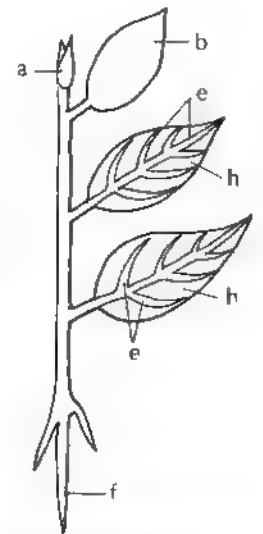
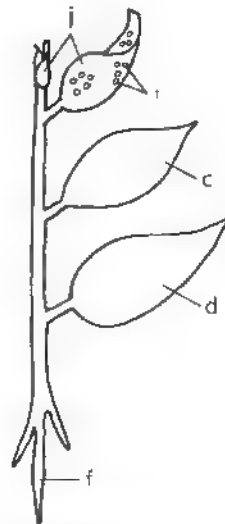
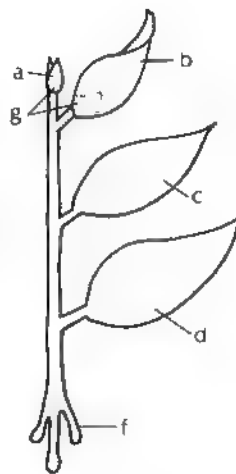
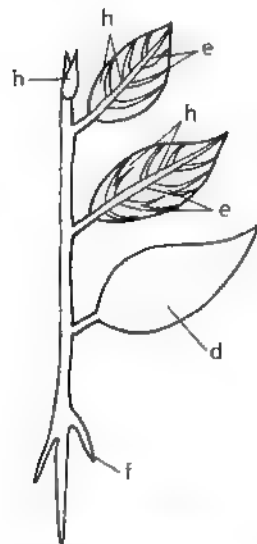
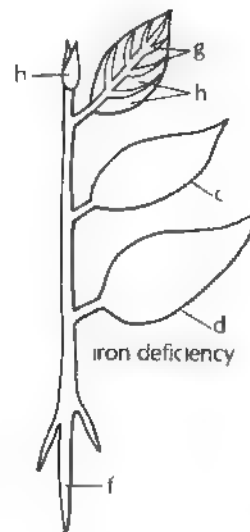
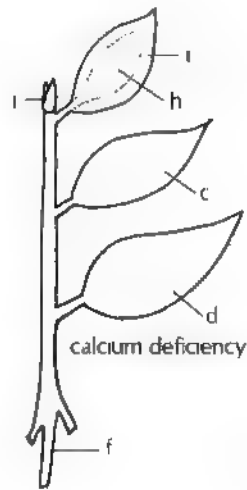
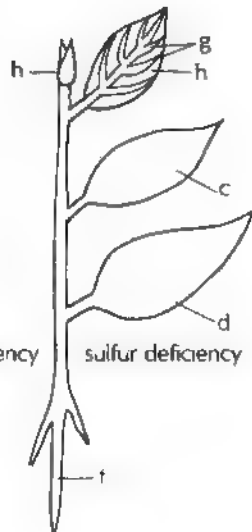
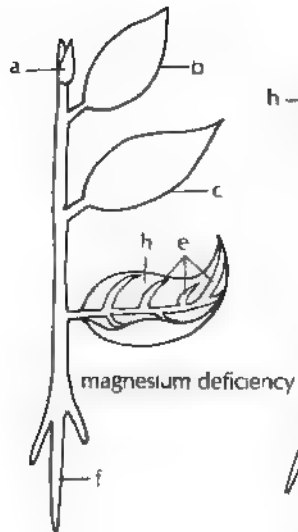
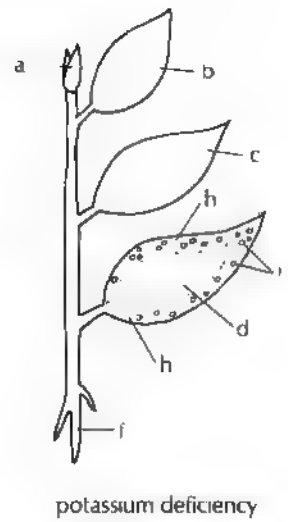
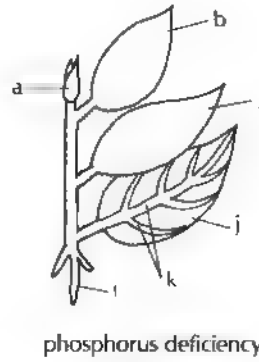
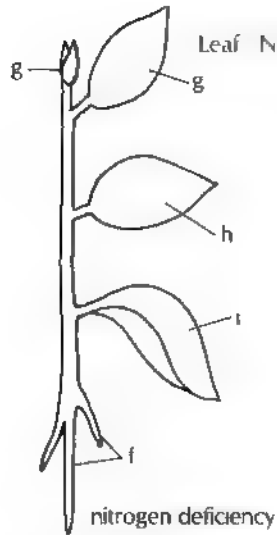
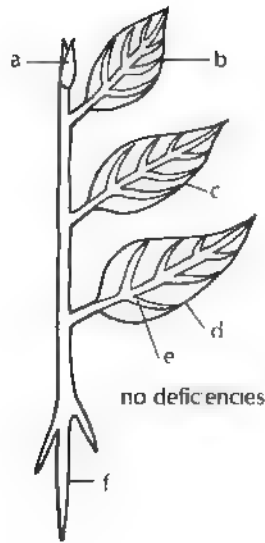
Copper. A rare deficiency, lack of copper produces dark green, twisted young leaves, which often have dead spots.

Molybdenum. Lack of this element produces chlorosis of old and midstem leaves, and eventually affects the young leaves.

COLOR CODE

green:	terminal bud (a), new leaf (b), middle leaf (c), old leaf (d), veins (e)
tan:	roots (f)
light green:	chlorosis (g)
yellow:	late-stage chlorosis (h)
brown:	dead tissue (i)
dark green:	pigment accumulation (j)
red-purple:	anthocyanin pigmentation (k)
red-brown:	damaged tissue (l)

Leaf Nutrient Deficiency Symptoms



Flower Initiation in Response to Daylength

Plants are classified as short-day, long-day, or day-neutral in terms of their flowering response to daylength (photoperiod). Most plants are **day-neutral**. They are not induced to flower by either long or short photoperiods. In the tropics, where photoperiods do not change nearly as much as in temperate regions, most plants are day-neutral or long-day in their response to photoperiod.

Short-day Plants

It has been found that rather than the length of daylight time, it is actually the length of the dark period (night length time) that induces flowering in short-day plants. If poinsettias are briefly illuminated during their long-night period, the flowering response is not induced. **Short-day** plants grow vegetatively (a) during long-day periods and flower (b) during short-day periods. Some examples of short-day plants are poinsettia (*Euphorbia pulcherrima*), thanksgiving cactus (*Schlumbergera truncata*), chrysanthemum (*Chrysanthemum*), lamb's quarters (*Chenopodium album*), cocklebur (*Xanthium strumarium*), strawberry (*Fragaria*), and many varieties of rice (*Oryza*).

The nature of the flowering stimulus in short-day plants is not yet known. However, the stimulus most likely involves an interaction between flower-inhibitor and flower-promoter type hormones. The evidence that ini-

tiation of flowers involves hormones is that the signal can be perceived by one mature leaf.

Using cocklebur plants, if one mature leaf (c) is exposed to short days while the rest of the plant is exposed to long days, flowering will result. Furthermore, by grafting a branch from a cocklebur plant given short days onto a cocklebur plant given long days, flowering is induced in the stems given long days.

Long-day Plants

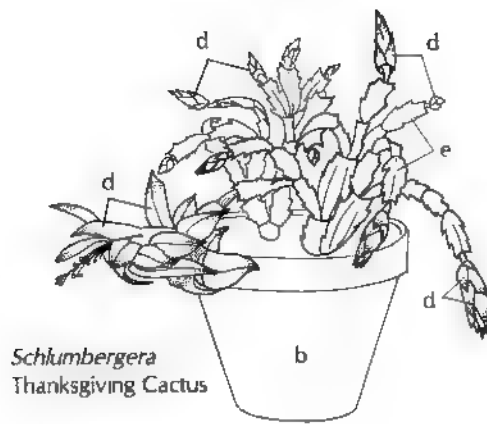
Plants that require **long days** (short nights) for flowering include spinach (*Spinacia oleracea*), winter barley (*Hordeum vulgare*), winter wheat (*Triticum aestivum*), oats (*Avena sativa*), perennial ryegrass (*Lolium perenne*), clover (*Trifolium pratense*), coneflower (*Rudbeckia*), dill (*Anethum graveolens*), rose-of-sharon (*Hibiscus syriacus*), petunia (*Petunia*), and all **biennials**. Biennials are plants with a 2-year growth cycle. They require cool winter temperatures the first year, and long days the second year for flower induction.

Some plants cannot be induced to flower by exposure to critical daylength periods until a certain age is reached. Depending on the species, some trees are not "flower-mature" until 5 to 40 years of age. For example, a sugar maple tree (*Acer saccharum*) may not flower until it is 30 years old, but it can live 200 to 300 years.

COLOR CODE

red: tepals (d)
green: stems (a, f, l), leaves (g, j), peduncle (k)
tan: fruit(h)
yellow: rays (l)
brown: flowers (m)

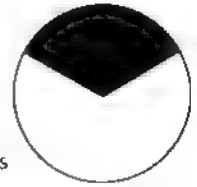
Flowering in Response to Day length



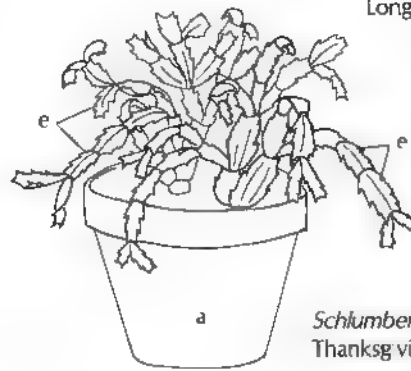
Schlumbergera
Thanksgiving Cactus



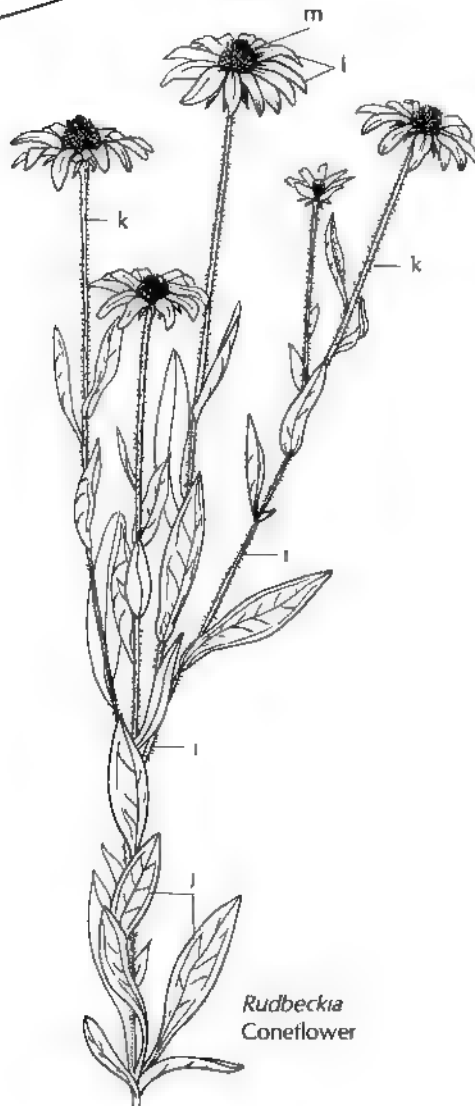
Short Days



Long Days



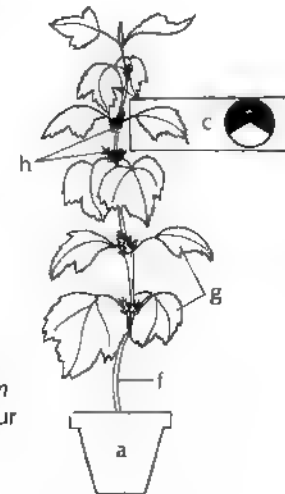
Schlumbergera
Thanksgiving Cactus



Rudbeckia
Coneflower



Xanthium
Cocklebur



Flower Structure

Parts of a Flower

Peduncle. The stalk that attaches the flower to the plant axis is called a **peduncle** (a). A **pedicel** is the stalk of a single flower in a cluster (**inflorescence**) with the pedicels attached to a peduncle (see 98, 100, 109).

Receptacle. The enlarged part of the flower axis where floral parts are borne is the **receptacle** (b).

Sepals. The outermost whorl of floral parts are leaf-like structures called **sepals** (c). While usually green, they may be colored in some species (see 129, 130). Sepals protect the developing flower in the bud stage. All of the sepals, collectively, make up the **calyx**.

Petals. The second whorl of floral appendages are **petals** (d), which may be separate or partially fused together. Usually, they are showy and may be colored. All of the petals, collectively, make up the **corolla**.

Tepals. When the calyx and corolla look alike and are petal-like, they are called **tepals** (see 126, 128).

Perianth. This term is used to refer to the calyx and corolla together.

Stamen. A stamen consists of a stalk-like **filament** (e) with an **anther** (f), made up of, usually, 2 pollen sacs, at the upper end. The **connective** (g) joins the **pollen sacs** containing **pollen grains** (h) (see 31). All of

the stamens, collectively, are termed the **androecium** (= male household).

Pistil. A pistil is made up of stigma, style, and ovary. At the apex of the pistil is the **stigma** (i), where pollen grains adhere to the sugary, liquid excretions on the surface. Between the stigma and ovary is an elongated part of the pistil called the **style** (j). The **ovary** (k) consists of one or more **carpels**, which contain the ovules (see 28). Within the **ovule** (l), megaspores are formed, one of which develops into the embryo sac containing an egg (see 31).

After fertilization, the ovules develop into seeds (see 37). That part of the carpel where the ovules are attached is the **placenta** (see 28). A **locule** (m) is the chamber or space within a carpel. All of the pistils within a flower are called, collectively, the **gynoecium** (= female household).

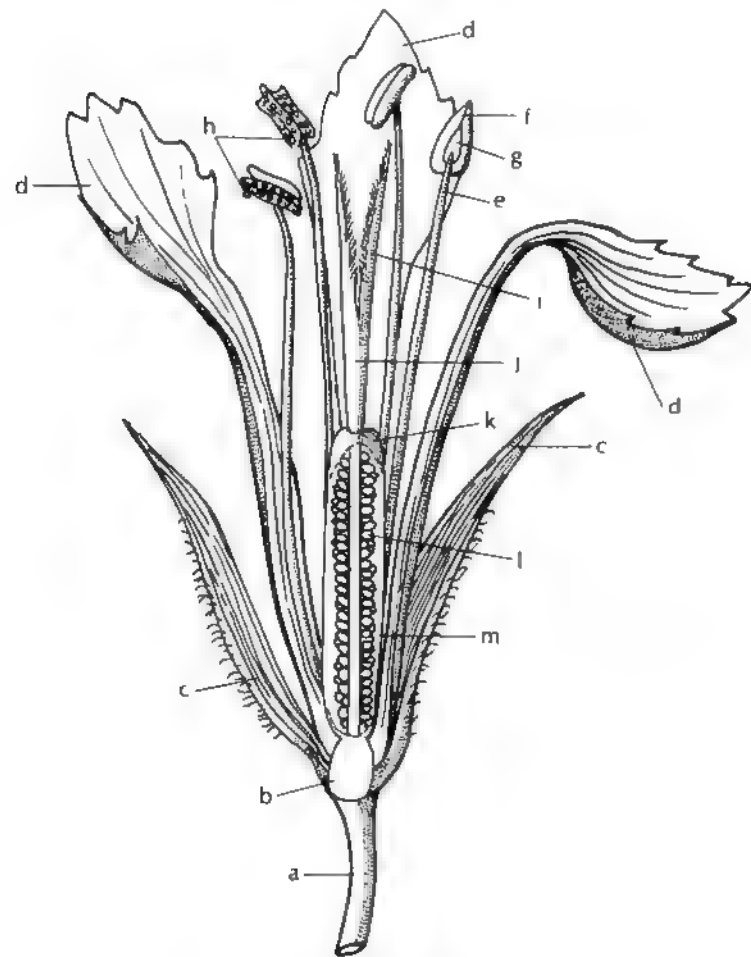
Number of Parts

In a broad generalization, dicot flowers tend to have floral parts in whorls of 4 to 5 and monocots in series of 3. For example, a dicot flower might have 4 sepals, 4 petals, and 8 stamens or 5 sepals, 5 petals, and 15 stamens. A monocot flower might have 3 sepals, 3 petals, and 6 stamens. When observing flowers, it is interesting to determine number patterns. Numbers of floral parts are also used in "keying out" plants (plant identification).

COLOR CODE

light green:	peduncle (a), stigma (i), style (j)
white:	receptacle (b), filament (e), ovary (k), ovules (l)
green:	sepals (c)
optional:	petals (d)
yellow:	anther (f), connective (g), pollen (h)

Flower Structure



Parts of a Flower
vertical section
diagram

Flower Structure Variations

Types of Flowers

Unisexual (Imperfect). A unisexual flower has either staminate (male) (a) or pistillate (female) (b) structures.

Bisexual (Perfect). A bisexual flower has staminate (a) and pistillate (b) structures.

Monoecious (= of one house). An individual plant with separate (unisexual) staminate and pistillate flowers is termed **monoecious** (see 94).

Dioecious (= of two houses). The term, **dioecious**, is used when a species has separate staminate-flowered plants and pistillate-flowered plants (see 105).

Polygamomonoecious. An individual plant with bisexual flowers plus staminate or pistillate unisexual flowers is **polygamomonoecious** (poly = many; gamete = sex cell).

Complete. A **complete flower** has staminate (a) and pistillate (b) structures, plus sepals (c) and petals (d).

Incomplete. An **incomplete flower** lacks one or more floral parts. The incomplete flower shown lacks petals.

Ovary Positions

Superior. The **superior ovary** (f) of the pistil is above the site of attachment of other floral parts (stamens, sepals, petals).

Inferior. The **inferior ovary** (f) is below the site of attachment of other floral parts.

Half-inferior or **Half-superior**. These are flowers that show varying degrees of ovary (f) position from partially superior to partially inferior.

Placentation

Axile. By fusion of 2 or more carpels (g), the ovules (h) are attached to the placenta (i) at the central axis (**axile placentation**).

Free Central. Fused carpels (g) have lost their inner walls and the placenta (i) is located in the center (**free central placentation**). Examples are members of the pink family (Caryophyllaceae, see 87) and nightshade family (Solanaceae, see 111, pepper).

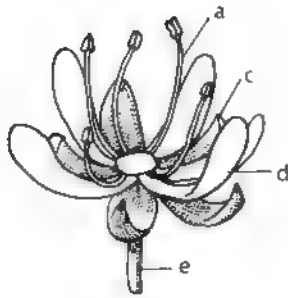
Basal. The placenta (i) is located at the base of the ovary (**basal placentation**).

Parietal. The placenta (i) is located on the inner walls of carpels, which do not extend into the center of the ovary (**parietal placentation**).

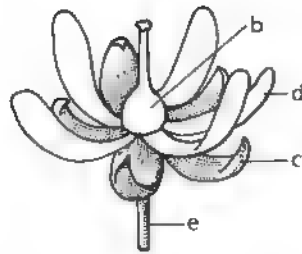
COLOR CODE

yellow:	stamen (a)
light green:	pistil (b), ovary (f), carpel wall (g), ovules (h)
green:	sepals (c), peduncle (e)
blue:	petals (d)
white:	ovules (h), placenta (i)

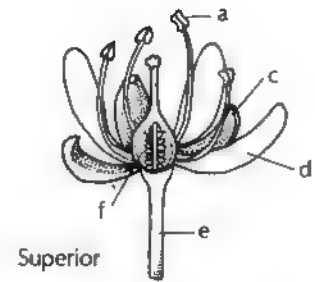
Flower Structure Variations



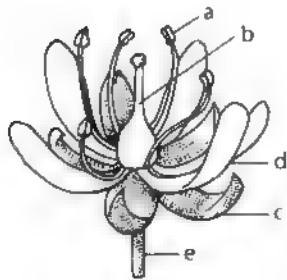
Unisexual
(imperfect)
staminate



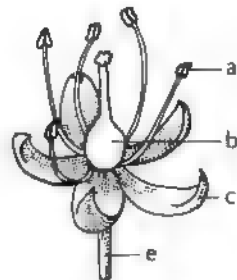
Unisexual
(imperfect)
pistillate



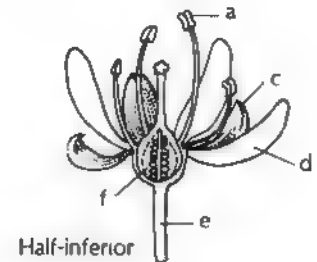
Superior



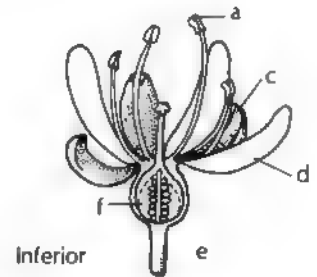
Bisexual
(perfect)
complete



Bisexual
(perfect)
incomplete

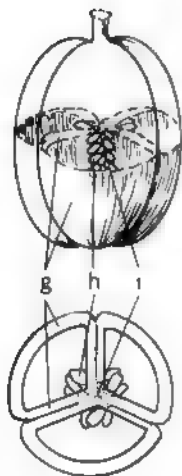


Half-inferior

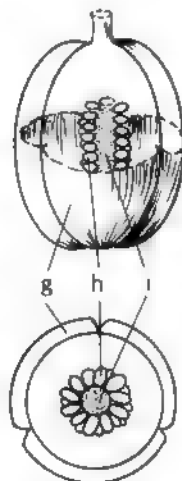


Inferior

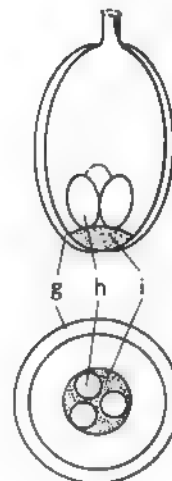
Types of Flowers



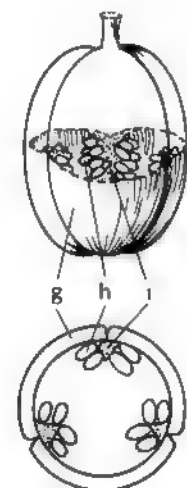
Axile



Free Central



Basal



Parietal

Placentation

Ovary Positions

Flower Development

Flower Bud

Early Stage. Above the peduncle (a), upright bracts (b) cover the sepals (c). The sepals enclose the developing petals (d), anthers (e), and the column of fused staminal filaments (f).

Intermediate Stage. At this stage, the receptacle (g) expands and a young pistil (h) within the column (i) can be seen. At the top of the pistil, stigmas (j) form, the style (k) begins to elongate, and the ovary (l) enlarges.

Late Stage. The folded petals (m) emerge from the sepals (n). Within, the filament column (p) has elongated and the stigmas (q) have emerged as the style (r) elongates. The superior ovary (l) has developing ovules (s) within the carpels.

Mature Flower

Bracts (b) are separate from the basally fused sepals (n) and the five petals (m) are expanded. The fully-formed fused filament column (t) protrudes above the petals. Anthers (o) are fully mature on short filaments (u), which separate from the column. Five stigmas (q) on a divided style (v) rise above the column.

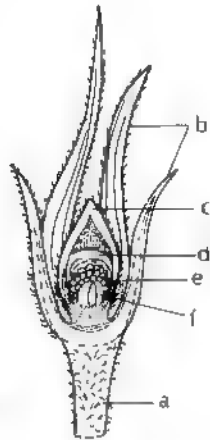
Anthesis. is the term used for the time when a flower comes into full bloom. It is a time when the flower is fully expanded.

COLOR CODE

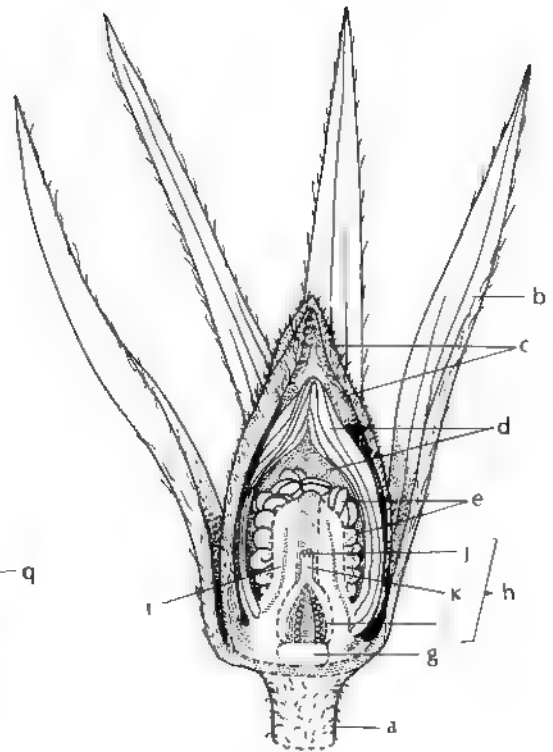
dark green:	peduncle (s), bracts (b), sepals (c)
light green:	petals (d), filament column (i)
white:	anthers (e), filament column (f, p), receptacle (g), pistil (h), stigma (j), style (k, r), ovary (l), ovules (s)
green:	sepals (n)
red:	petals (m)
yellow:	anthers (o)
dark red:	stigmas (q), filament column (t), filaments (u), style (v)

Flower Development

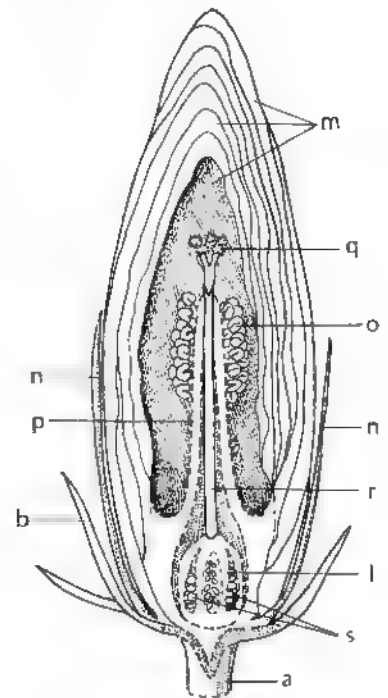
Flower Bud
early stage
vertical section
× 3



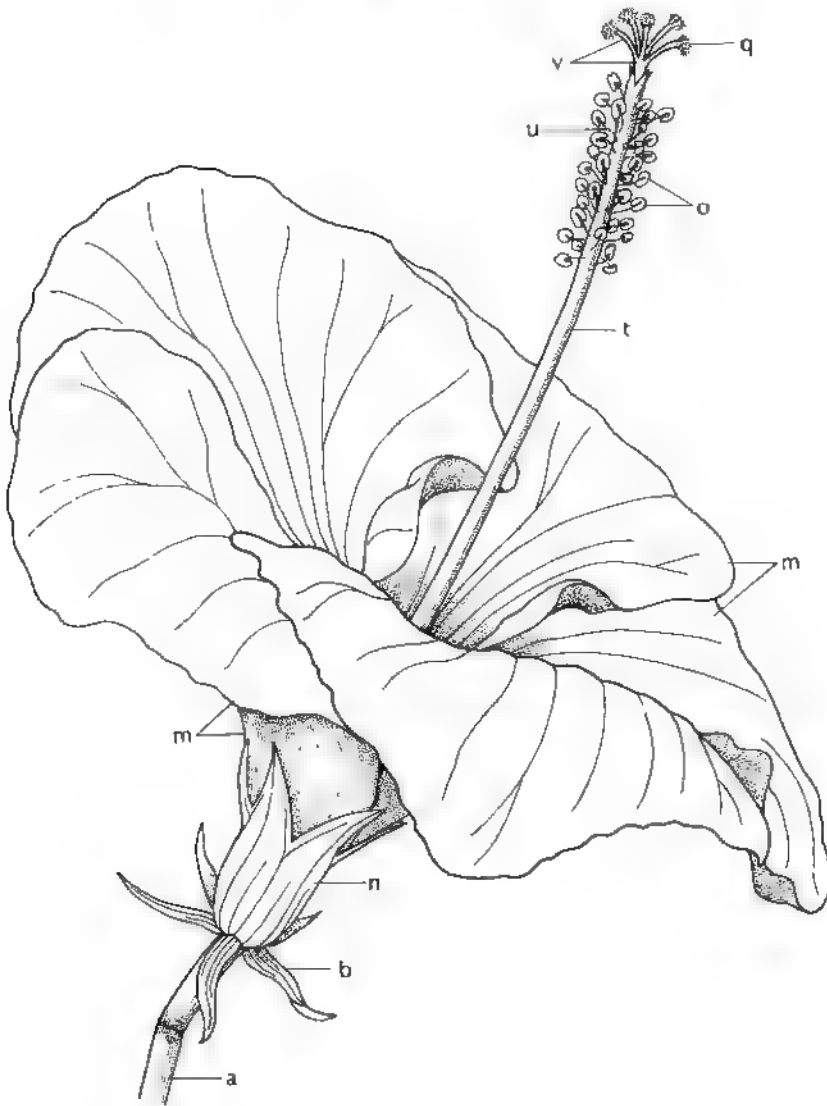
Flower Bud
intermediate stage
vertical section
× 5



Flower Bud
late stage
vertical section
× 1%



Mature Flower
× 1



Hibiscus rosa-sinensis
Rose-of-China

Flower—Meiosis

Each species has a specific number ($2n$) of chromosomes in the nucleus of each of its body (somatic) cells. Half of the chromosomes ($1n$) come from one parent and half ($1n$) from the other parent. For new body cells to form, $2n$ (diploid) cells divide by mitosis into more $2n$ cells.

For an individual to become a parent, it must produce $1n$ (haploid) cells that can fuse with $1n$ (haploid) cells from another individual. The process of producing haploid cells from diploid cells is called **meiosis**.

In higher plants, the end products of meiosis are haploid pollen grains in the anthers of the stamen and a haploid egg in each ovule of the pistil. In lower plants, the end products of meiosis are $1n$ (haploid) gametes (= sex cells).

Stages of Meiosis

Meiosis has 2 basic stages: (I), the reduction stage, and (II), the division stage. Unlike mitosis, during meiosis, chromosomes come together in pairs, called homologous pairs. Each chromosome of the pair has the same gene alignment and each represents a different parent. This pairing is significant because, during meiosis, "crossing over" (chiasmata) with an exchange of genes is possible (see 6).

It is now obvious that the $2n$ (diploid) number is an even number for normal pairing to occur. The cells that undergo meiosis are called "mother cells." Within each of the 2 stages of meiosis are 4 phases: prophase, metaphase, anaphase, and telophase.

Prophase I. During early prophase, the $2n$ chromosomes (a, b, c) become visible as threads and then come together in homologous pairs. (For simplicity, only 3 pairs of chromosomes are shown within a nucleus.) Then each chromosome separates to form

2 chromatids held together at the centromere (d). "Crossing over" (e) of chromatid strands results in chiasmata (sing.: chiasma), which are visible sites of exchanged genetic material (f).

Metaphase I. At this phase, the chromatids are positioned so that the centromeres are aligned on either side of the equatorial plane of the spindle apparatus (g).

Anaphase I. Next, the paired chromatids separate and move to opposite poles (h).

Telophase I. Lasting only a short time, telophase completes the reduction stage with the original number ($2n$) of chromosomes reduced to half ($1n$).

Prophase II. The second division stage of meiosis is essentially like mitosis (see 7).

Metaphase II. During this phase, the chromatids align in the center of the plane of the spindle.

Anaphase II. The centromeres (d) divide and chromosomes move to opposite poles (h) of the spindle.

Telophase II. By this phase, the chromosomes have completed their migration to the spindle poles. As a result, 4 $1n$ products are formed. The chromosomes (i, j, k) now have a different genetic makeup than the chromosomes of the original $2n$ cell.

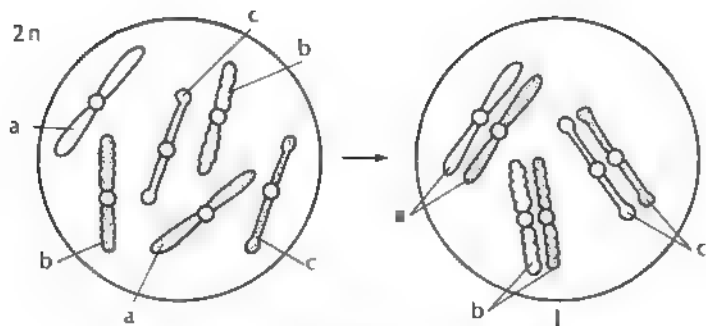
This meiotic description is characteristic of higher plants when 4 haploid products are formed. In flowering plants, in the ovule of the pistil, 3 of these nuclei usually disintegrate and the 4th divides (mitotically) repeatedly to form the nuclei of the embryo sac, one of which is the $1n$ egg nucleus. In the anther sac of the stamen, all 4 products of meiosis remain alive and develop into tetrads (4's) of $1n$ (haploid) pollen grains.

COLOR CODE

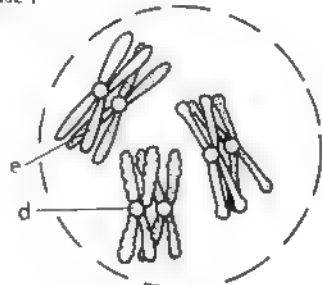
orange:	chromosomes (a)
yellow:	chromosomes (b)
green:	chromosomes (c)
purple:	centromere (d)
colorless:	spindle (g)
blue:	chromosomes (i, j, k)

Flower – Meiosis

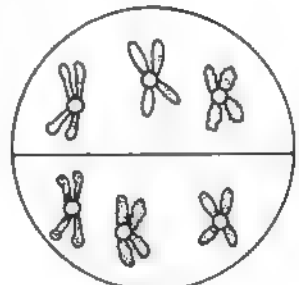
Phases of Meiosis



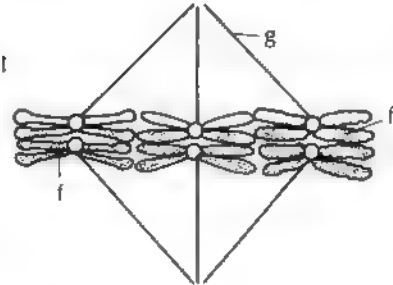
Prophase I



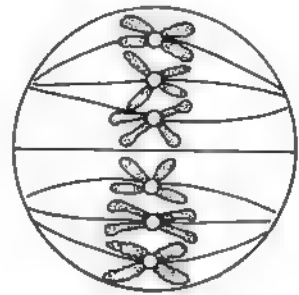
Prophase II



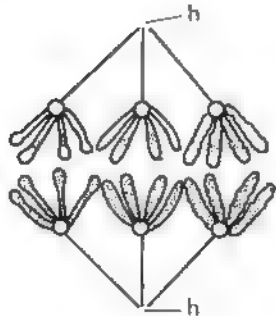
Metaphase I



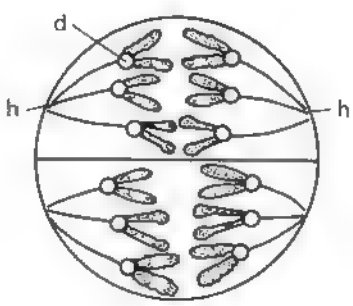
Metaphase II



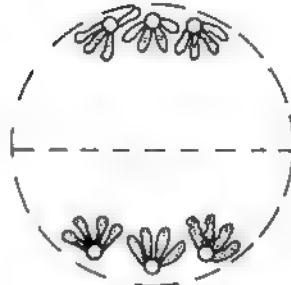
Anaphase I



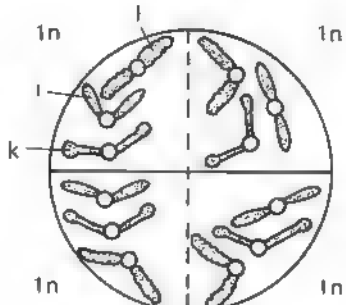
Anaphase II



Telophase I



Telophase II



Reduction Stage

Division Stage

Flower—Pollen Development

Young Stamen

Once flower primordia are initiated, stamens begin to develop. The stamen in a flower consists of a filament (a) and an anther (b) with, usually, 2 pollen sacs (c). Pollen formation takes place within the chambers (locules) of the pollen sac (microsporangium). Each chamber is surrounded by a layer of cells called the **tapetum** (d), which functions as a source of nutrition for the 2n microspore mother cells (e). During a double division (meiosis), each mother cell forms a tetrad of 4 1n (haploid) microspores (f), which develop into 4 pollen grains (male gametophytes).

Pollen Grain

In each pollen grain (g), nuclear division (mitosis) produces a large 1n vegetative nucleus (h) and a smaller 1n generative nucleus (i), which divides to form two 1n sperm nuclei, usually after the pollen grain germinates to form a pollen tube (see 37).

Mature Stamen

Depending on the stamen type, the anther wall (j) spontaneously opens (dehiscence) at a slit (k) to liberate pollen (l), or the anther wall breaks down, releasing pollen, or a portion of the anther lobe separates, leaving a pore (poricidal dehiscence).

Pollen Grain Types

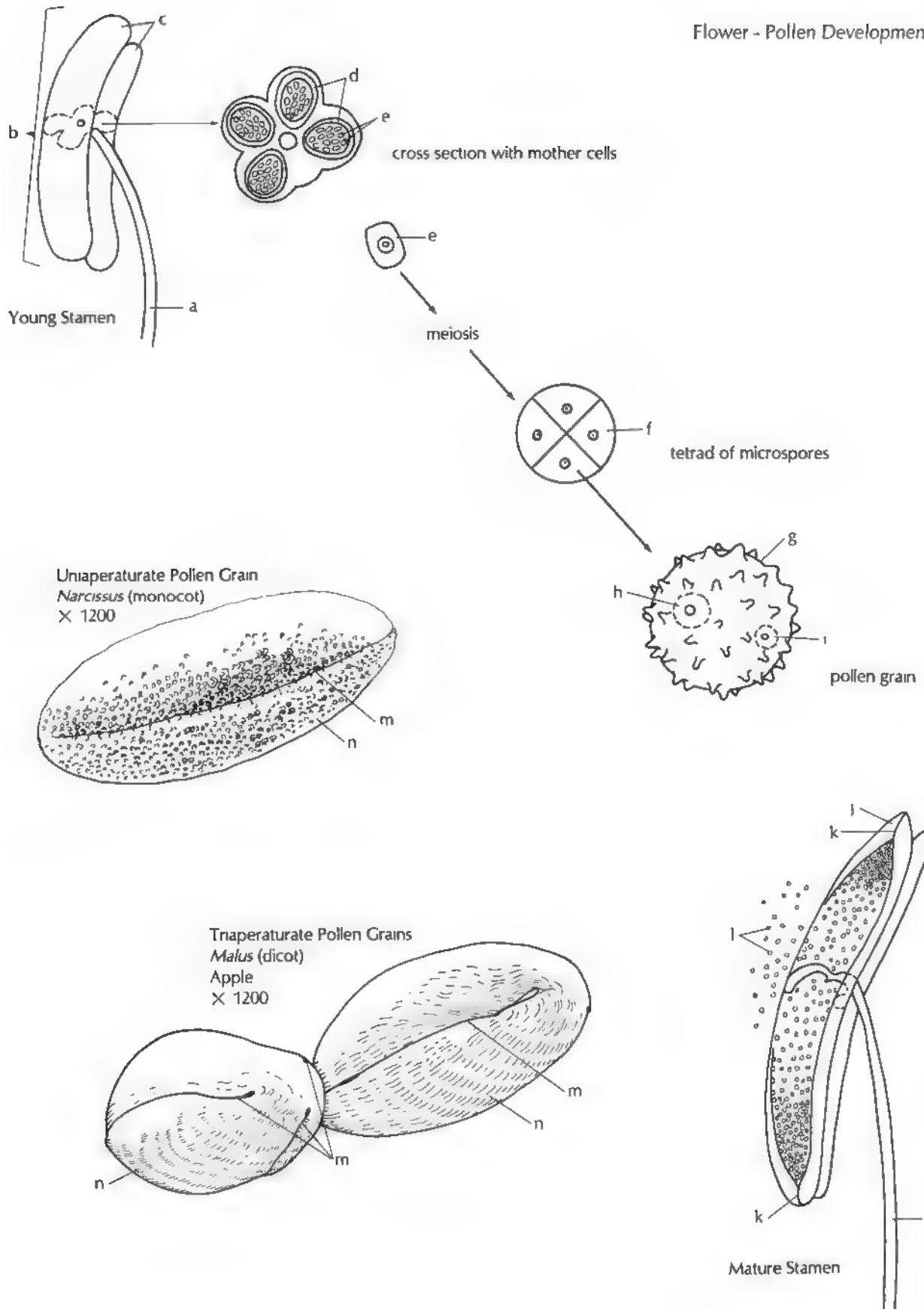
Pollen grains have one or more furrows (m) or thin strips where the pollen tube may emerge. In some pollen grains, the pollen tube may emerge from a pore in the furrow or a pore not associated with a furrow.

In flowering plants, the main types of pollen grains (n) are uniaperturate with one furrow and triaperturate with 3 furrows. Monocots and some primitive dicots have uniaperturate pollen grains. Most dicots have triaperturate pollen grains. Pollen grains vary from species to species in size, shape, and decoration of the outer wall (exine). Some pollen grains lack an exine. The study of pollen grains of past and present-day plants is called **palynology**.

COLOR CODE

white:	filament (a), microspore mother cell (e), microspore (f), anther wall (j)
light green:	anther pollen sacs (c)
orange:	tapetum (d), vegetative nucleus (h), generative nucleus (i)
yellow:	pollen grains (g, l, m, n)

Flower - Pollen Development



Flower—Ovule Development

Young Pistil

When flowering is initiated, the pistil begins to develop in the center of the flower. It consists of stigma (at top), style and ovary (at base). The ovary (a) of the pistil has one or more separate or fused carpels (b). Within the carpel are locules (c) where ovules (d) develop. Ovule development begins with meiosis in a $2n$ megaspore mother cell (e) within the center portion of a young ovule (megasporangium). The megaspore mother cell undergoes a double reduction/division (meiosis) to form a linear tetrad of $1n$ megaspores. Of these, usually 3 abort (f) with one megaspore (g) remaining.

Embryo Sac

The nucleus of the remaining megaspore divides repeatedly (mitosis) to form the 8 haploid ($1n$) nuclei of the embryo sac (female gametophyte, h). The central part of the ovule is vegetative tissue, nucellus (i). Surrounding the embryo sac are one or two layers of cells, the integuments (j), with a small opening at the base called the micropyle (k).

Mature Ovule

The 3 nuclei of most embryo sacs align into positions so that 1 near the micropylar end is the egg cell (l), 2 are nuclei of synergid cells (m) with associated filiform apparatus (n), 2 are polar nuclei (o), and 3 are nuclei of antipodal cells (p). The mature ovule within the pistil consists of the embryo sac (h) surrounded by nucellus (i) and integuments (j). It is attached to the placenta (q) by a stalk called the funiculus (r).

COLOR CODE

light green:	ovary (a), integuments (j) placenta (q), funiculus (r)
white:	carpel (b), locule (c), ovule (d), aborted megaspores (f), synergids (m) filiform apparatus (n) polar nuclei (o), antipodals (p)
gray:	mother cell (e) megaspore (g), embryo sac (h)
tan:	egg (l)
orange:	nucellus (i)

d — Megasporangium with 2n megaspore mother cell

Flower - Ovule Development

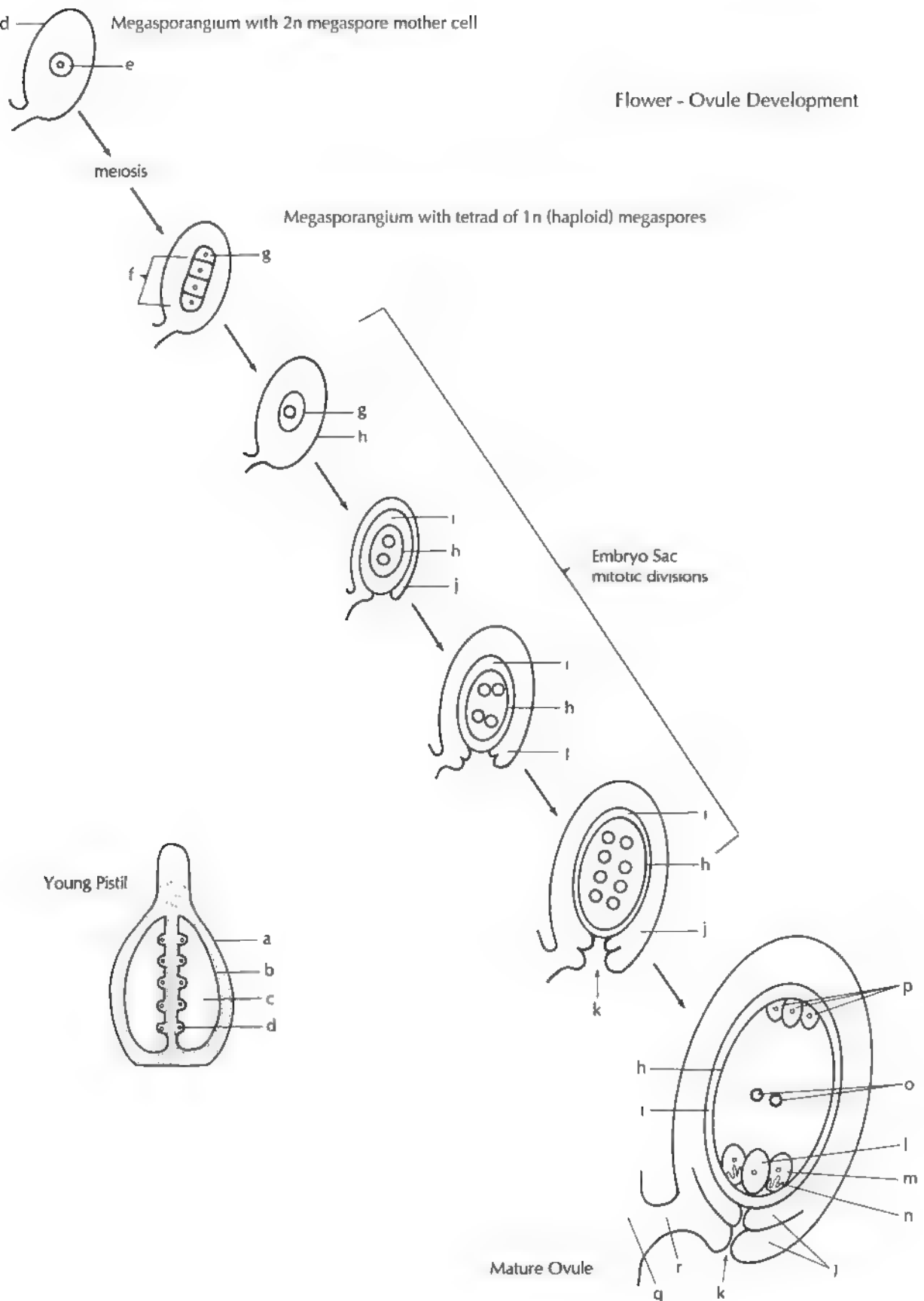
meiosis

Megasporangium with tetrad of 1n (haploid) megaspores

Embryo Sac
mitotic divisions

Young Pistil

Mature Ovule



Flower Pollination by Insects

The transfer of pollen from an anther to the stigma of a pistil is called **pollination**. Some flowers are self-fertile and self-pollinated. **Cross-pollination** takes place when pollen is transferred to another plant. This provides genetic diversity. Within flowers of an individual plant, the time of pollen and stigma maturity may not coincide. Thus, all the pollen may be shed before the stigma matures and pollen must be transferred from another plant for fertilization to take place.

Insect Pollination

Although primitive seed plants, such as conifers, are wind-pollinated, fossil evidence shows that when flowering plants appeared, primitive insects such as beetles pollinated them. Beetles have biting mouthparts, and pollination of primitive flowers involved devouring pollen and other floral parts. Flowering plants developed structures that attracted other types of insects. As flowering plants diversified, there was a parallel diversity of insect specializations. Insects developed various mouthpieces, some in the form of hollow tubes (probosci).

Nectar. In some plants, nectar (a sugar-water solution) was secreted. Then, concealed nectar at the bases of petal, stamens, or ovaries appeared in some plants. Some plants developed unisexual flowers (see 28) secreting nectar, although most flowers pollinated by insects are bisexual (see 28). Some flowers developed long nectar tubes or spurs (see 115, j), that attract insects with long probosci such as moths and butterflies.

Petals. Many flowers secrete a strong scent. Scent produced in the petals differs among types of plants. In contrast to a green background, other colors appeared in flower petals. Some flowers, such as *Iris*, developed lines or hairs on petals (see 129, g) directed toward the nectar glands (see 101, k). These are commonly called **nectar guides** (see 130, n).

Specific insects were attracted to plants that developed corolla structures in the form of "landing platforms" (see 113, d), "overnight traps" (as in some arum family, Araceae, plants), and those that mimic the shape, scent, and color of female insects, a common strategy in the orchid family (Orchidaceae).

Sepals. Some plant flowers developed stout sepals with overlapping bracts around the ovary. This is apparent in the arum family (see 127).

Stamen. Plants produced pollen grains with a sticky coating and also the capacity to produce excessive pollen as food to lure pollinating insects. Some flowers developed fertile and sterile pollen on separate anthers to prevent wasteful expenditure of resources.

Pistil. As plants diversified, there was a change in ovary position from an exposed superior position to one lower or below other floral parts (inferior ovary) (see 28). Pistils with inferior ovaries may have long styles, which elevate the stigma (see 113, sage flower).

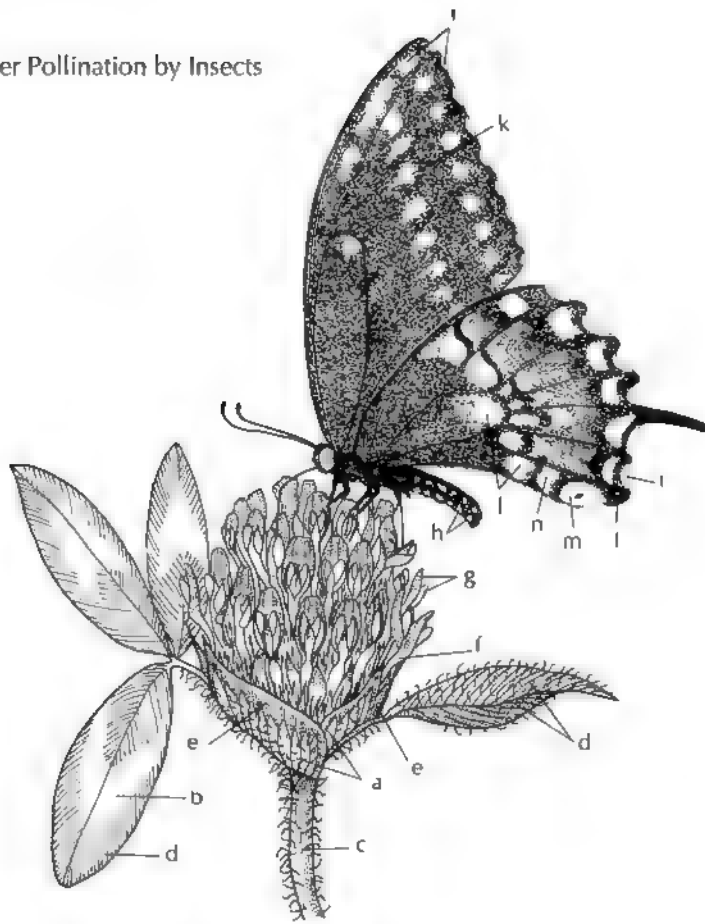
Butterfly-pollinated Flowers

Butterflies are attracted to flowers aggregated in a head of many small flowers. The butterfly tongue is a long coiled tube adapted to sucking nectar from long-tubed flowers. Pollen is dusted on the tongue and head of the butterfly. The flickering appearance of flowers shaken by the wind is associated with the presence of nectar to butterflies. Flowers attractive to butterflies have sweet scents and are usually blue, dark pink, yellow-red, and purple. The illustrated example is red clover (*Trifolium pratense*) with a female black swallowtail butterfly (*Papilio polyxenes asterius*).

COLOR CODE

white:	sepal ribs (a), petal tube (f)
pale green:	leaflet center (b)
green:	peduncle (c), leaflets (d), sepals (e)
pink-purple:	petal lobes (g)
yellow:	spots on abdomen (h), rows of outer forewing spots (i), row of outer hindwing crescents (j)
orange:	row of inner forewing spots (k), row of inner hindwing spots (l), single spot (m), row of spots between j and m
blue:	row of muted areas across hindwing (n)

Flower Pollination by Insects



Trifolium pratense
 Red Clover
 inflorescence with butterfly
 X 1½

Flower Pollination by Insects (continued)

Bee-pollinated Flowers

Bees perceive flowers that reflect yellow-green, blue-green, blue-violet, and ultraviolet light. Petals of flowers with colored lines or dark marks guide bees toward nectaries. Rows of dots, stripes, crosses, and checks on flowers attract bees.

The most common type of bee-pollinated flower has a "landing platform" such as the two-lipped (bilabiate) petals found in the flowers of the mint family (see 113, Lamiaceae), or falsely two-lipped petals such as the fused petals of banners and keel found in the pea family (see 100, Fabaceae).

Bee-pollinated flowers have light, sweet, pleasant scents. Bees collect pollen (as a protein source to feed larvae) as well as sugar-rich nectar, which is converted to the honey on which they feed. Honeybees have a so-called pollen basket. Their bristly hairs attract pollen grains that they then brush with their legs into the basket on either side of their bodies. When baskets are tightly packed with pollen, they return to the hive. Of course, not all of the pollen is collected; much is brushed off on the next flower visited insuring pollination.

Bees are the most efficient insect pollinators, as they will visit every flower in a mass of plants until the nectar is exhausted. Some flowers secrete nectar only at a specific time of day when fertilization is to take place; consequently, bees visit these flowers only at that time. Some flowers contain nectar in long spurs and are visited by long-tongued bees (see 115, *Linaria*).

For an illustrated example, see iris family (120, Iridaceae), flag (*Iris*) with a bumblebee (*Bombus affinis*).

Moth-pollinated Flowers

Highly scented and white, green, or yellow flowers are attractive to moths. Night-flying (nocturnal) moths pollinate night-blooming flowers. Nectar at the base of long petal tubes (a) is available only to insects such as moths with very long tubular mouth parts (f). Many moth-pollinated flowers are star-shaped with a central funnel to the nectary.

The illustrated example is a tobacco flower (*Nicotiana*) with a Carolina sphinx moth (*Protoparce sexta*). (Moth adapted with permission from the *National Geographic*).

Fly-pollinated Flowers

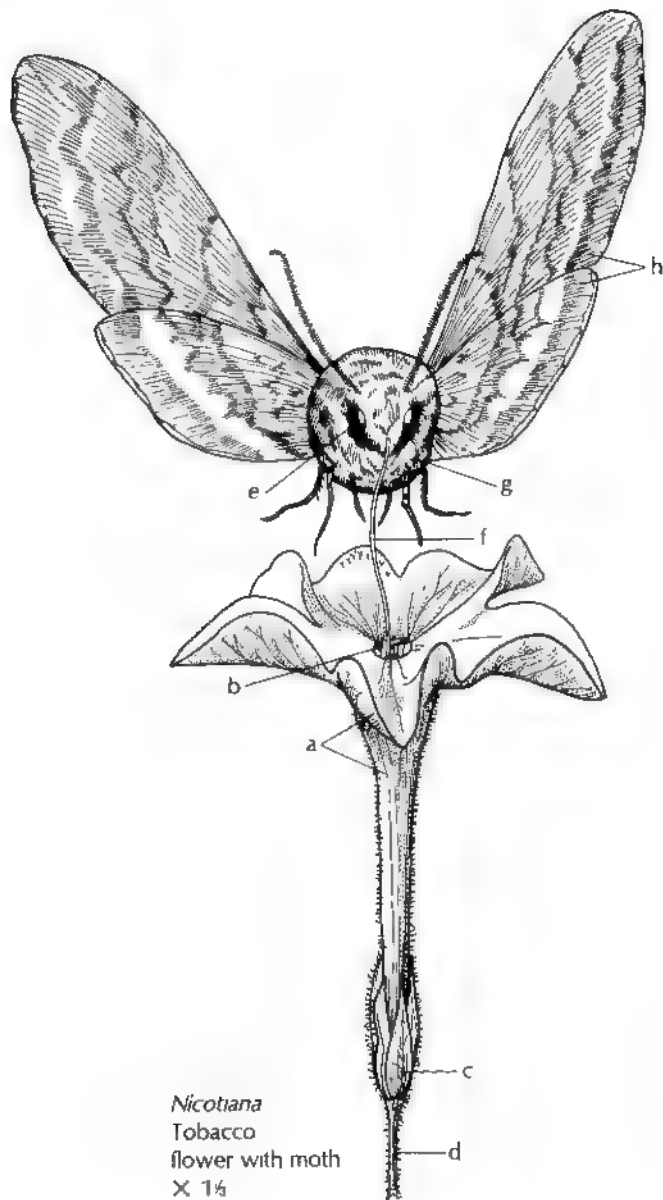
Many flowers pollinated by flies have exposed nectar. Some have sweet odors, and other flowers have odor and color (pink, purple, green) of decomposing organic matter, which attracts flies. Usually flies are attracted to white, yellow, and yellow-green flowers.

In the arum family (see 127, Araceae), the odor and color of the flower cluster (spadix), with its bract (spathe, n) attract flies. In some species, a fly visitor slides down the spadix, is trapped in the spathe, and is released within a day, carrying mature pollen.

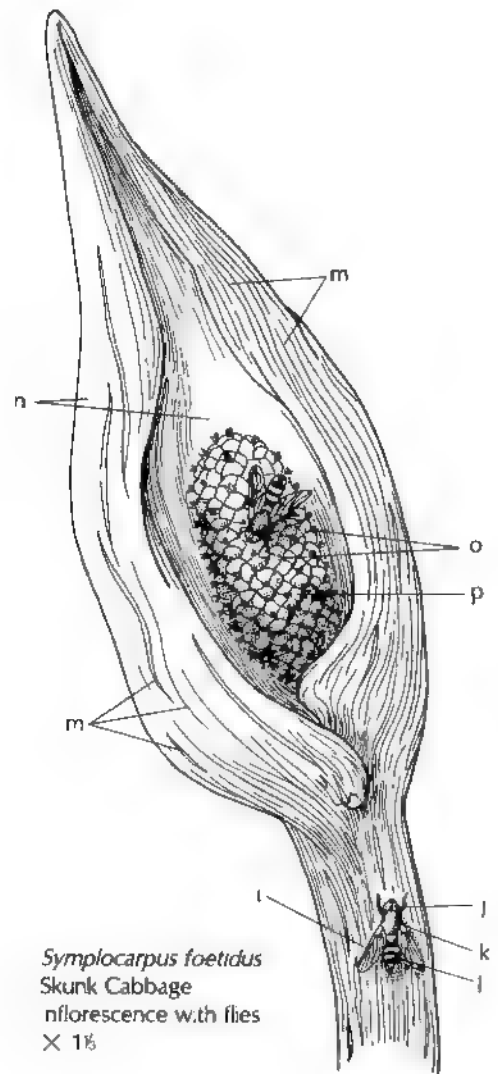
The illustrated example is a skunk cabbage (*Symplocarpus foetidus*) inflorescence with two syrphid carrion flies (*Allograpta obliqua*).

COLOR CODE

white:	petal tube (a), fly wings (i), spadix flowers (p)
yellow:	stamens (b, o)
green:	calyx (c), peduncle (d), fly thorax (k), lines on spathe (m)
light gray:	moth eyes (e), moth tongue (f), moth thorax (g), moth wings (h)
tan:	fly eyes (j)
orange:	fly abdomen (l)
purple:	spathe (n)



Flower Pollination by Insects



Flower Pollination by Wind

Wind Pollination

From the fossil record, we learn that wind pollination was a later development in flowering plants. To change from pollination by insects to pollen transferred by wind currents, loss of color, petals, nectaries, scent, and the sticky covering on pollen grains became apparent. With the exception of sexual structures, flower parts developed that were much smaller in size.

The stamens increased in size and number, and some stamens developed very long filaments. Huge amounts of tiny, dry pollen grains developed. Since wind is a chance pollinator, that is, more is better, the stigma of the pistil increased in size and often became feathery (plumose) or divided. The number of carpels in the ovary also increased in some flowers.

Bisexual flowers changed to separate staminate (male) and pistillate (female) unisexual flowers and increased in number. Unisexual flowers tended to aggregate in clusters or to form catkins (aments). In some dicots, staminate and pistillate flowers formed on separate plants (**dioecious**) (see 106, staghorn sumac).

Wind-pollinated Flowers

Some of the monocot herbs that are wind-pollinated are members of the grass (Poaceae, see 123), cattail (Typhaceae), and rush (Juncaceae) families. Bisexual or staminate unisexual flowers are elevated on slender stalks above the vegetative parts of the plant.

Wind pollination is also found in trees, such as elms, ashes, and hackberries of the elm family (see 82, Ulmaceae). Birches, ironwoods, alders, and hazelnuts of the birch family (see 84, Betulaceae), beeches, oaks, and chestnuts of the beech family (see 83, Fagaceae) and poplars of the willow family (see 95, Salicaceae) are also trees with wind pollination.

The notorious ragweed (*Ambrosia*) in the aster family (Asteraceae, see 119) is an obvious herbaceous dicot example. Hayfever sufferers are familiar with its wind-blown pollen.

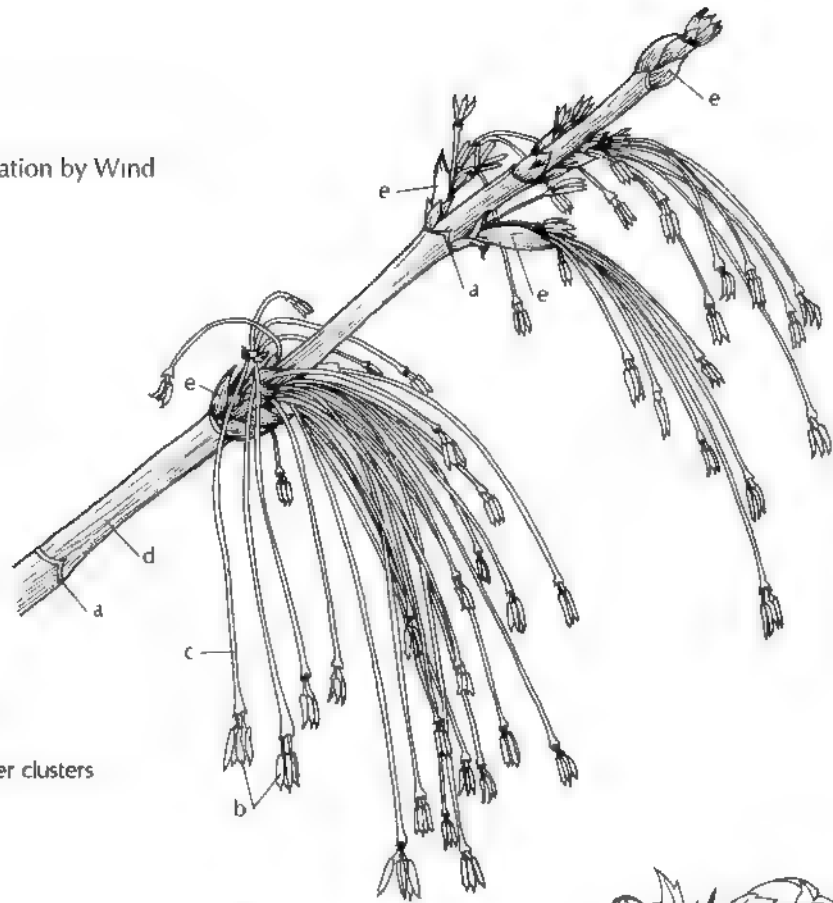
Willows (*Salix* spp.) have unisexual reduced flowers in catkins but have nectar glands and are insect-pollinated. Staminate flowers, which form in clusters, swing loosely on an axis and open during the windy spring period before the leaves expand. Vestiges of bisexual flowers remain in some wind-pollinated flowers that have reduced, sterile structures of the opposite sex (see 105, maple family, Aceraceae).

The illustrated example is a box elder (*Acer negundo*), which is dioecious. The flower in a cluster of staminate (male) flowers has pendant anthers (b) on a long pedicel (c). On a tree with pistillate (female) flowers, the compound leaves (l) begin to expand as the flower develops. The pistillate flowers has fused, lobed sepals (j), a double ovary (k) and divided stigmas (i).

COLOR CODE

tan:	leaf scars (a, f)
yellow:	anthers (b)
yellow-green:	pedicel (c), shoots (d, g), bud scales (e, h), leaflet (i), sepals (j)
tan-green:	ovaries (k)
white:	stigmas (l)

Flower Pollination by Wind



Acer negundo
Box Elder
staminate flower clusters
× 2



Acer negundo
Box Elder
pistillate flower clusters
× 2

Flower Pollination by Birds and Bats

Bird and Bat Pollination

A flower pollinated by birds or bats usually possesses both staminate (male) and pistillate (female) reproductive structures (bisexual). Some have sweet, fleshy bracts surrounding the flower as well as pollen and nectar. Others may have imitation pollen made of proteins and/or starch.

While some flowers attract birds or bats, animals such as slugs, snails, earthworms, mice, rats, squirrels and opossums pollinate other flowers. Gerbils, mice and shrews pollinate various South African *Protea* species. These plants produce low-lying flowers of dull colors.

The attraction for animals is food, i. e., copious amounts of nectar that contains not only sugar, but vitamins, amino acids and other nutrients. While an animal is gathering nectar, pollen grains with hooks and spines and sticky coatings adhere to the animal's coat to be transferred to another flower resulting in pollination.

Bird-pollinated Flowers

Birds pollinate many tropical and subtropical plants. Flowers attractive to birds are usually bright red or orange. Some have striking color contrasts. Hummingbird-pollinated flowers are mainly red, a color not usually perceived by insects. Bird-pollinated flowers have abundant nectar and are without scent. Some are tube flowers with a basal swelling filled with nectar. The ovaries may be inferior or separated from the nectaries,

as in spur flowers, so that damage does not incur while the pollinator is visiting.

Some bird visitors feed on small insects attracted by the nectar. Some bird-pollinated flowers are very large, while others are small. Some plants have sturdy perches near flowers, while others have freely swinging flowers, which attract hovering birds.

Generally, bird-pollinated flower forms are of the two-lipped (bilabiate) type, tubular flowers, flowers with a protruding bottlebrush stamen arrangement, or flowers with nectar in spurs.

The illustration example is fuchsia (*Fuchsia magellanica*) with a Brazilian hermit hummingbird (*Phaethornis eurynoma*).

Bat-pollinated Flowers

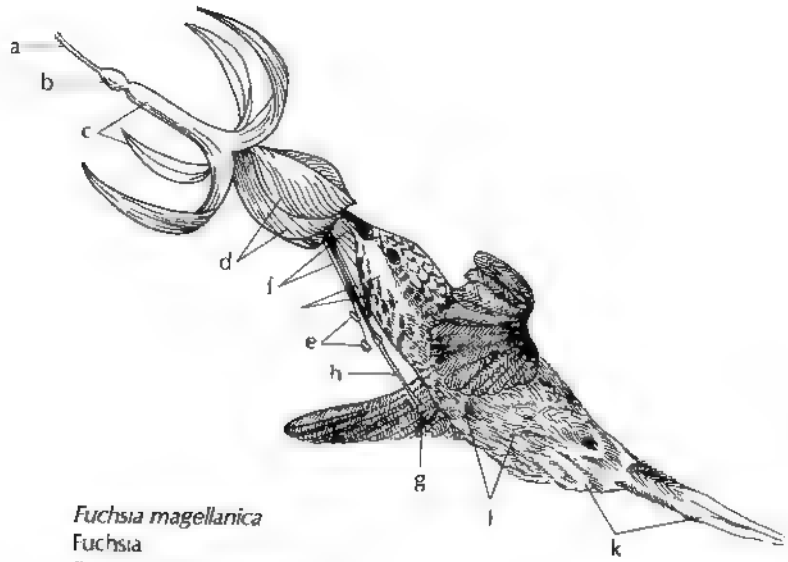
Bats pollinate many large tropical herbs and trees. These flowers are usually arranged in a manner easily accessible to flying bats. Flowers attractive to bats bloom at night, have large amounts of nectar and pollen, are usually pale in color, may have a musky or fruity odor, and are strong enough to support a bat. Bat-pollinated flowers are bell-shaped, open saucer-shaped with many stamens, or possess suspended flowers with stamens bunched in a protruding brush.

The illustration example is a saguaro cactus (*Carnegiea gigantea*) flower with a long-nosed bat (*Leptonycteris sanborni*).

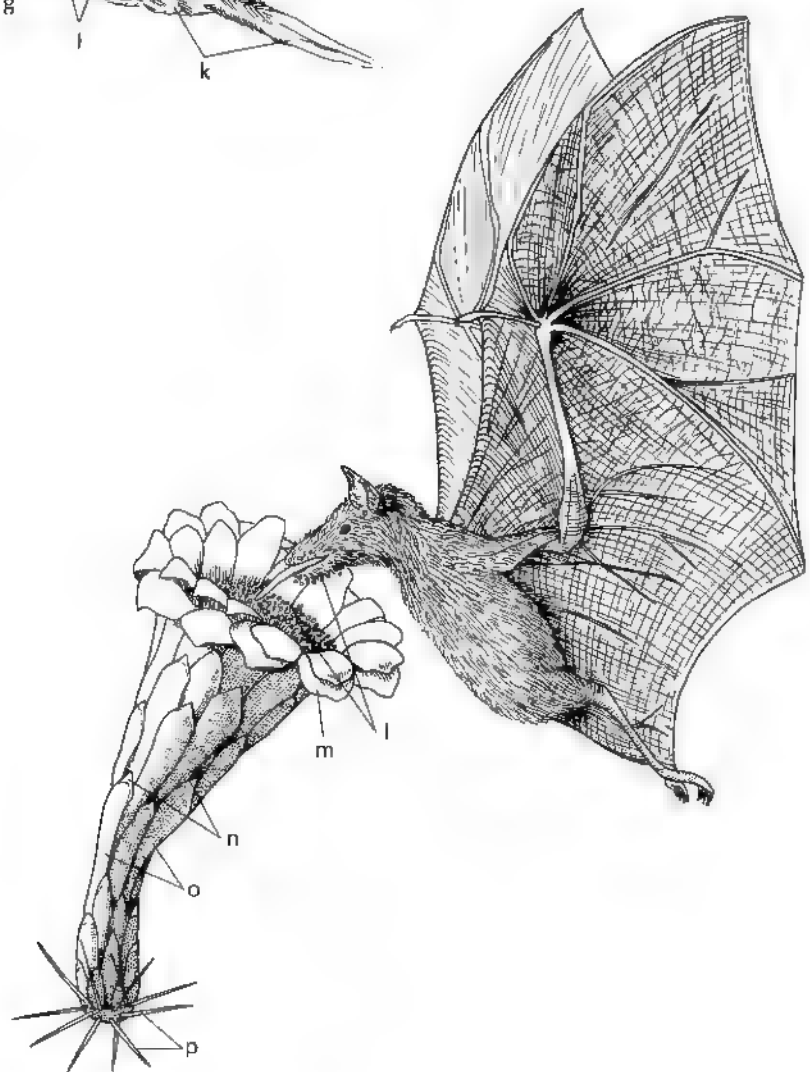
COLOR CODE

green:	peduncle (a), ovary (b)
red:	sepals (c), filaments (f), style (h), bat tongue
red-purple:	petals (d)
yellow:	anthers (e), stigma (g), pollen(l), spines (p)
yellow-green:	bracts (o)
light orange:	area below bird's eye (i), breast feathers (j), tips of bracts (n)
white:	unshaded areas of tail, near tail (k), tepals (m)
light brown:	remaining bird feathers, not colored above
brown-orange:	entire bat, except tongue and pollen

Flower Pollinated by Birds & Bats



Fuchsia magellanica
Fuchsia
flower with hummingbird
X 2/3



Carnegiea gigantea
Saguaro Cactus
flower with bat
X 2/3

Flower—Fertilization and Embryo Development

Fertilization

Pistil. During pollination, pollen (a) from a stamen is transferred to a stigma (b). The stigmatic surface is usually covered with secretory cells (c) possessing copious amounts of sugars needed for growth of the pollen tube (d). The pollen tube grows within the style (e) to the ovule (f) in the ovary (g). There, it enters the embryo sac (h) at the opening (**micropyle**) between the integuments (i). Within the pollen tube are the 1n (haploid) tube nucleus (j) and two 1n (haploid) sperm nuclei (k, l). After entry into the embryo sac, the pollen tube tip bursts and discharges the 2 sperm nuclei. Simultaneously, one or both synergid cells (m) disintegrate (see 32).

Embryo Sac. Within the embryo sac double fertilization occurs. The egg (n) nucleus (o) fuses with one sperm nucleus (k) to form a 2n (diploid) zygote (q). The other sperm nucleus (l) unites with the 2 polar nuclei (p) to form a 3n (triploid) **primary endosperm nucleus** (r).

Embryo Development

Globular Stage Embryo. The primary endosperm nucleus divides repeatedly to form many 3n free, floating nuclei (s). Meanwhile, the zygote starts to divide, forming a basal cell (t), which develops into a **suspensor** (u) to elevate the developing embryo in the sac and to transport nutrients. An apical cell divides to form a globular mass of cells (v).

Heart Stage Embryo. Walls develop around the free endosperm nuclei, forming the cellular endosperm (w). The endosperm cells contain stored food reserves such as hormones, starch, proteins, oils, and fats. In dicots, the embryo becomes heart-shaped with the formation of cotyledon primordia (x).

Torpedo Stage Embryo. As the young embryo elongates, the vascular systems for the young root (y) and shoot (z) are formed.

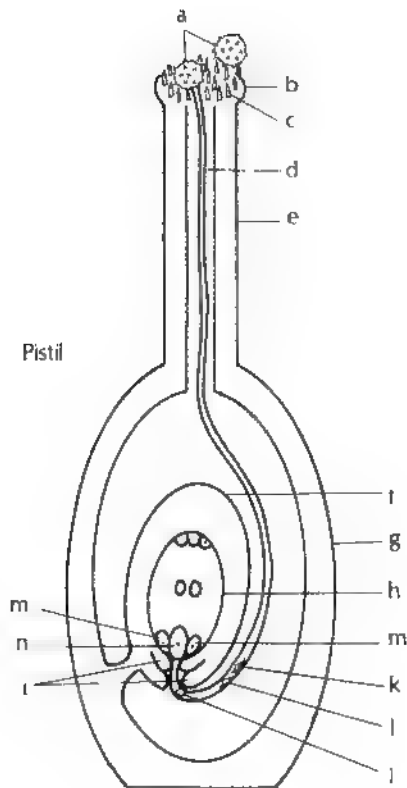
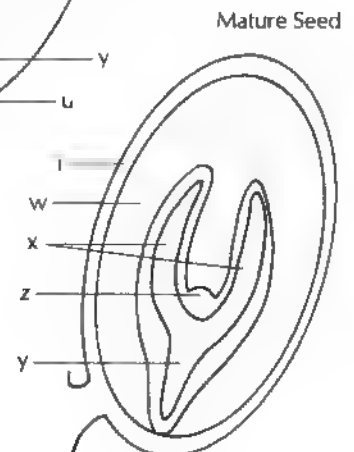
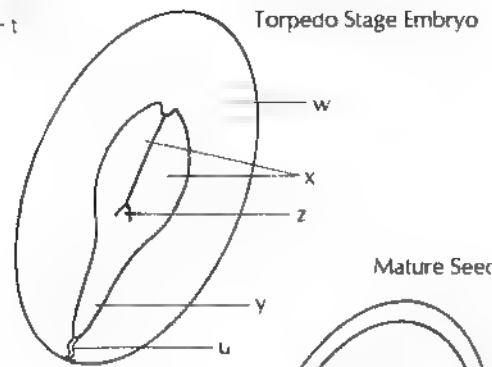
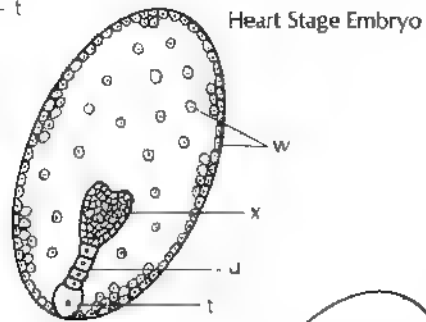
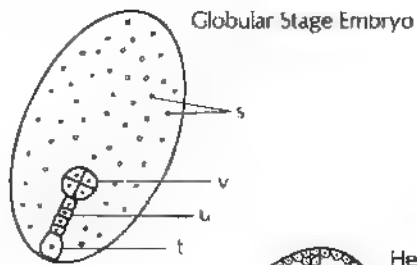
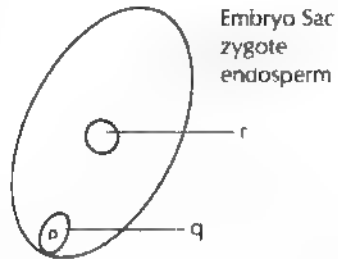
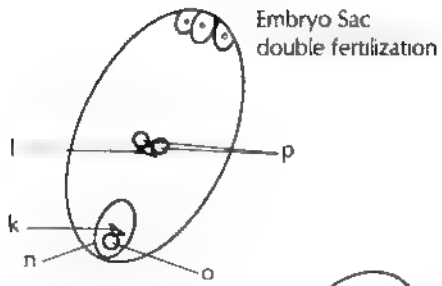
Mature Seed

In the mature seed, the integuments (i) of the embryo sac have developed into the protective **seed coat** (testa). The embryo illustrated has 2 seed leaves (**cotyledons**, x) of a dicot. (Monocots usually have 1 seed leaf or cotyledon, see 40, corn seed)

COLOR CODE

yellow:	pollen (a), pollen tube (d), tube nucleus (j)
light green:	stigma (b), secretory cells (c), style (e), ovule (f), ovary (g), integuments (i)
gray:	embryo sac (h)
white:	synergids (m), polar nuclei (p), zygote (q), embryo (t, u, v, x, y, z)
tan:	egg (n)
red:	sperm nuclei (k, l), egg nucleus (o)
orange:	endosperm (r, s, w)

Flower – Fertilization and Embryo Development



Fruit—Dry Types

A **fruit** is the seed-bearing structure in flowering plants (conifer seeds are borne in a cone).

Indehiscent, Dry Fruit Types

An **indehiscent, dry fruit** does not open at maturity. The tissues are composed of parenchyma and/or sclerenchyma (see 8) at maturity.

Achene. An achene (a) is a type of one-seeded fruit with a thin wall (pericarp).

Grain (Caryopsis). A grain (c) is a type of achene found in grasses (see 123, grass family, Poaceae), which originates from a superior ovary (see 28).

Cypsela. An achene that originates from an inferior ovary, and commonly has a hairy pappus (d) present, is a cypsela (e).

Nut. An achene-type fruit, the nut (f) is hard and “bony,” and may result from a compound ovary.

Samara. The samara is a type of winged achene, which may be single, as in elm (*Ulmus*, h), or double, as in maple (*Acer*, i).

Schizocarp. Carpels of a compound ovary break apart into **mericarps** (j), which function as achenes in the schizocarp type fruit.

Nutlet. A small nut is called a nutlet (k).

Dehiscent, Dry Fruit Types

A dehiscent, dry fruit opens to release seeds at maturity. The fruit splits under tension along definite lines or breakage points.

Follicle. Composed of a single pistil, the follicle (l) splits along one line (see 77, *Magnolia grandiflora*).

Legume. A legume (m) originates from one carpel, which splits along two lines, and is the fruit type of the pea family (see 100, Fabaceae). A type of legume, the seeds of a **loment** (n) are partitioned into sections. The carpel of a **spiral legume** (o) coils.

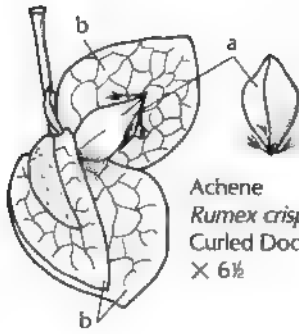
Capsule. Capsules have more than one carpel and are classified by the mode of opening (dehiscence). The **septicidal** capsule (p) opens in the plane of carpel union. A **loculicidal** capsule (r) opens around a horizontal line. A **poricidal** capsule (t) releases seeds through pores at the top.

Silique. A silique has 2 narrow pieces (**valves**, u) separated by a partition (**replum**, v). A rounded form is called a **silicle** (w, x). These are fruits of the mustard family (see 96, Brassicaceae).

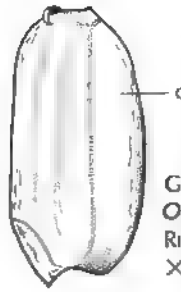
COLOR CODE

tan:	achene (a), cypsela (e), nut (f), schizocarp mericarps (j), nutlets (k), spiral (o), septicidal capsule (p), seeds (s), valve (x)
white:	grain (c), pappus (d), replum (v, w)
red-brown:	bracts (b)
brown:	cup (g), legume (m), loculicidal capsule (q), seeds (y)
yellow-tan:	single samara (h)
green:	double samara (i), circumscissile capsule (r), valve (u)
yellow:	follicle (l), loment (n), poricidal capsule (t)

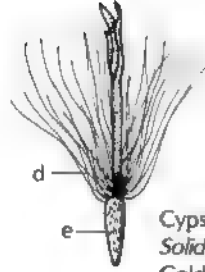
Dry Fruit Types



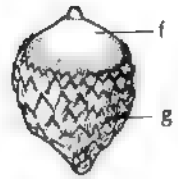
Achene
Rumex crispus
Curled Dock
× 6½



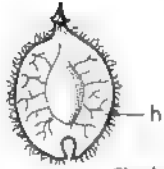
Grain
Oryza sativa
Rice
× 5½



Cypsel
Solidago
Goldenrod
× 10

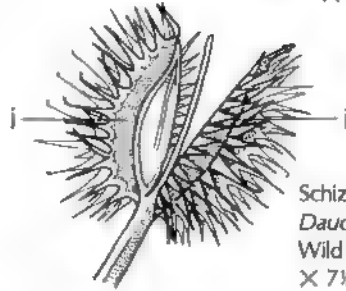
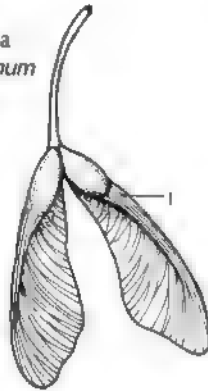


Nut
Quercus velutina
Black Oak
× 1



Double Samara
Acer saccharinum
Silver Maple
× ½

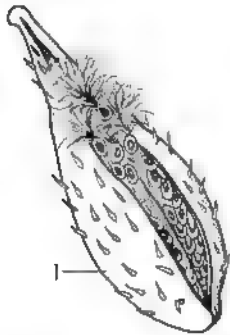
Single Samara
Ulmus americana
American Elm
× 2



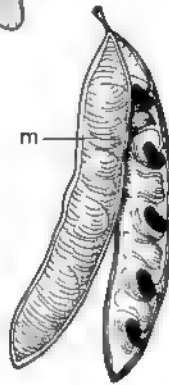
Schizocarp
Daucus carota
Wild Carrot
× 7½



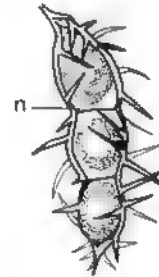
Nutlet
Mentha
Mint
× 16



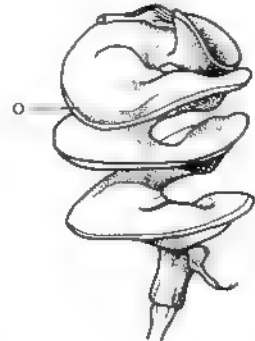
Follicle
Asclepias
Milkweed
× ½



Legume
Robinia pseudoacacia
Black Locust
× ½

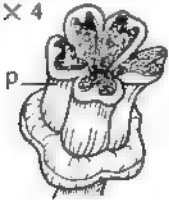


Loment Legume
Mimosa
Mimosa
× 2½

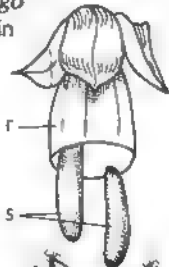


Spiral Legume
Medicago
Black Medick
× 4½

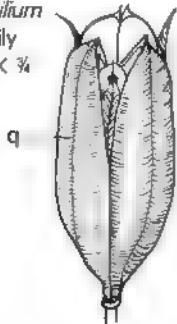
Septicidal Capsule
Rhododendron
Rhododendron
× 4



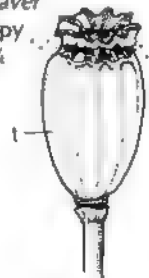
Circumscissile Capsule
Plantago
Plantain
× 6



Loculicidal Capsule
Lilium
Lily
× ¾

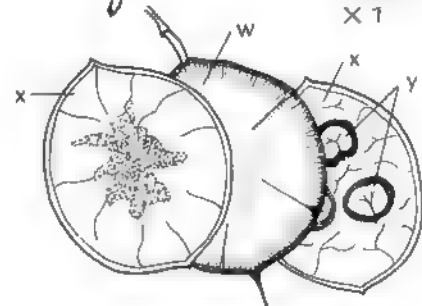


Poricidal Capsule
Papaver
Poppy
× ¾



Silique
Brassica
Mustard
× 1

Silicle
Lunaria
Honesty
× 1



Fruit—Fleshy Types, Compound

Fleshy Fruit Types

The ovary or fruit wall (**pericarp**) consists of an outer layer (**exocarp**), middle layers of parenchyma (**mesocarp**), and an inner layer (**endocarp**). The parenchyma tissues are filled with sugars, starch, and/or fats at maturity.

Berry. The entire pericarp (b, c) of a berry is fleshy. There may be one or more carpels and seeds (d).

Pepo. This berry with a hard-rind pericarp composed of exocarp (e) and endocarp is a pepo fruit. It is derived from an inferior ovary (see gourd family, Cucurbitaceae, 94).

Hesperidium. A leathery-rinded berry, the hesperidium exocarp (h) of compact collenchyma contains oil glands. There is a spongy mesocarp (i) and an endocarp (j), which produces juice sacs. This type, commonly called citrus, is found in the rue family, Rutaceae (see 107).

Drupe. The drupe fruit ovary wall develops into a fleshy mesocarp (n) and a stony endocarp (o) over usually one seed.

Pome. A pome has a pericarp of cartilaginous endocarp (r) lining the seed (q) cavities (locules), which are surrounded by fleshy parenchyma exocarp (s). Outside the inferior ovary wall is an expanded floral tube (t) of fleshy parenchyma. (For flower to fruit development, see rose family, Rosaceae, 99).

Compound Fruit

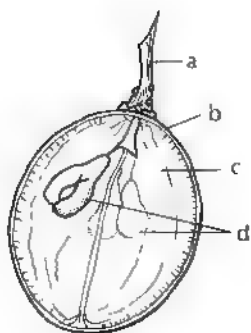
Aggregate Fruits. The separate carpel of one flower stays together as a unit in an aggregate fruit. Examples are an aggregate of drupelets (x), as in black raspberry fruits, an aggregate of achenes, as in strawberry fruits, and an aggregate of follicles (see 77, *Magnolia grandiflora*).

Multiple Fruits. The carpels of separate flowers in a cluster stay together as a unit in multiple fruits as in a multiple of achenes in osage-orange and pineapple.

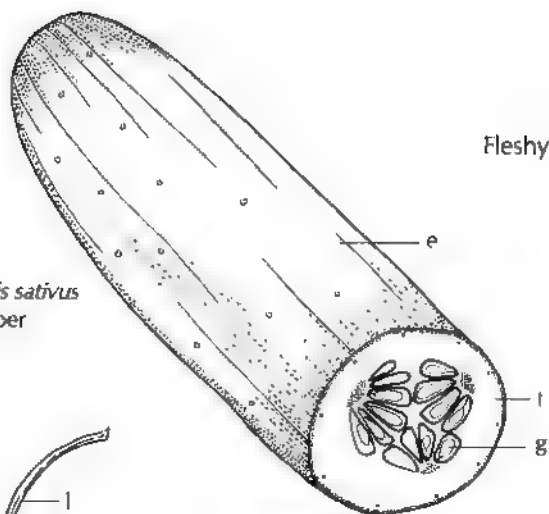
COLOR CODE

tan:	pedicel (a), peduncle (l, p), seed (d, k, y), endocarp (o)
purple:	exocarp (b)
white:	mesocarp (c, f, i, z), seed (g), exocarp (s), floral tube (t)
green:	exocarp (e), peduncle (v), sepal (w)
yellow:	exocarp (h)
pale yellow:	endocarp (j, r)
red:	exocarp (m), mesocarp (n), epidermis (u)
brown:	seed (q)
dark blue:	drupelet exocarp (x)
yellow-green:	epidermis (y)

Berry
Vitis
Grape
× 1½

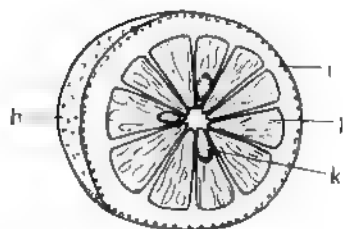


Pepo
Cucumis sativus
Cucumber
× ½

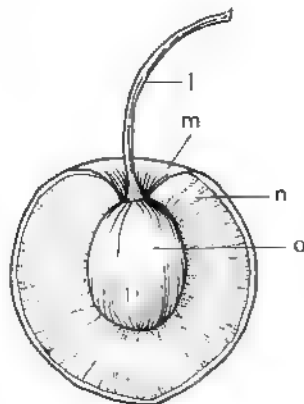


Fleshy Fruit Types

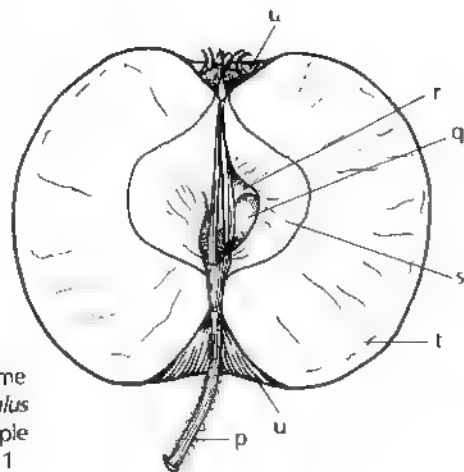
Hesperidium
Citrus limon
Lemon
× ¼



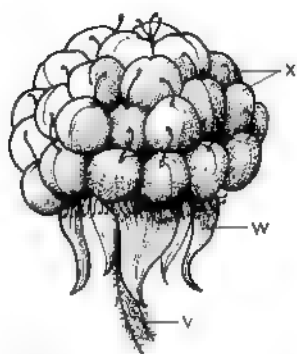
Drupe
Prunus avium
Cherry
× 1½



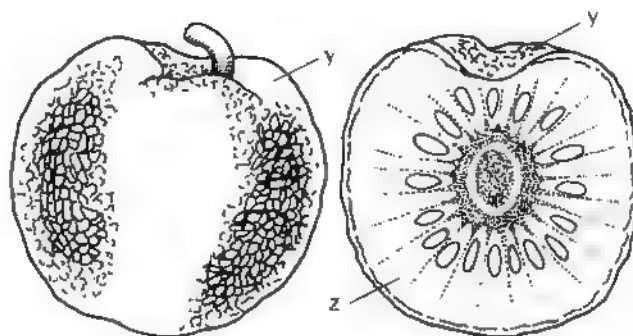
Pome
Malus
Apple
× 1



Compound Fruit



Aggregate Fruit of Drupelets
Rubus occidentalis
Black Raspberry
× 3



Multiple Fruit of Achenes
Maclura pomifera
Osage-orange
× ½

Seed Structure and Germination

A **seed**, which develops from an ovule, consists of a partially developed sporophyte plant (**embryo**) and none or various amounts of food storage tissue (**endosperm**) covered by a protective seed coat (**testa**).

Dicot Seed

The embryo usually has two seed leaves (cotyledons). As the bean seed is split in half, only one cotyledon (a) is shown. In the bean and pea seedlings, two cotyledons (a, b) can be seen. Between the cotyledons is the hypocotyl axis (c) with the shoot meristem (epicotyl) at one end, the root meristem at the other end. An undeveloped root (**radicle**, d) may be present. The **plumule** (e) of the bean seed will develop into stem (f) and leaves (g) in the seedling.

Nutritive/food storage tissue (endosperm) sustains the germinating embryo until roots and leaves are functionally developed. Endosperm cells contain mostly starch with lesser amounts of proteins, oils, and/or fats. In bean seeds, the cotyledons, which occupy most of the space, store the food reserves, with the scant endosperm consisting mostly of protein.

The seed coat (h) is made up of the ovules' fused integuments. An opening (**micropyle**) between the integuments sometimes leaves a pore (i). Where the ovule was attached to the placenta, by a stalk (**funiculus**), there is sometimes a scar (**hilum**, j). Usually the seed coat is very thick and may be colored.

Monocot Seed

Usually monocot seeds have one cotyledon. A grain fruit (caryopsis) is used as a monocot example. The embryo includes one cotyledon called the **scutellum** (k), an outer protective cylindrical leaf (**coleoptile**, l), which encloses young leaves (m) over the shoot apical meristem (n), and a protective cap (**coleorrhiza**, o) over the root apex (p).

The outermost layer of the endosperm, the **aleurone** (q), contains most of the protein of the seed, while the remaining endosperm (r) is mostly starch. In grains, the fruit coat (s) is made up of fused integuments and pericarp.

In the monocot grain of rice (*Oryza sativa*), white rice (polished rice) is devoid of aleurone ("protein jacket") and consists of embryo and starchy endosperm only. In contrast, brown rice (not polished) has the aleurone present and is thus much better nutritionally because the aleurone layer contains the bulk of the seed storage proteins (6 to 12 % of dry weight). White rice is primarily starch.

Conifer Seed

The embryo axis (t) consists of cotyledons (u) enclosing the shoot apical meristem at the tip, the hypocotyl, and the root apex (v) at the base. Conifer seeds have no endosperm; the embryo is surrounded by megagametophyte tissue (w) and enclosed by a seed coat (x).

Germination

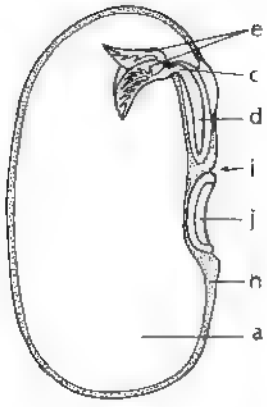
Seed germination is the growth of the embryo, resulting in emergence of a shoot (**epicotyl**) and root (**radicle**). To germinate, the seed must be alive, not dormant, have a suitable temperature, adequate moisture, an oxygen supply, and for some species, light.

Once the radicle has emerged from the seed coat, the seedling either develops with its cotyledons above ground (**epigeous**), as in bean (a) and pine (u), or below ground (**hypogeous**), as in pea (b) and corn (s). The cotyledons of epigeous seedlings produce chloroplasts and function photosynthetically until true leaves develop. Cotyledons of hypogeous seedlings provide food for the developing plants.

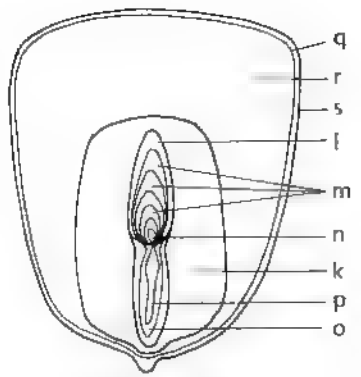
COLOR CODE

Seeds:	white
Seedlings:	
green:	cotyledons (a, b, u), leaves and stipules (g), leaf (m), embryo axis (c, t), stem (f), coleoptile (l)
tan:	seed coat (h, x)
white:	roots
yellow:	fruit coat (s)

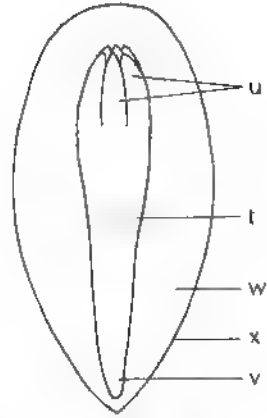
Seeds



Dicot, ½
Phaseolus
Bean
× 3

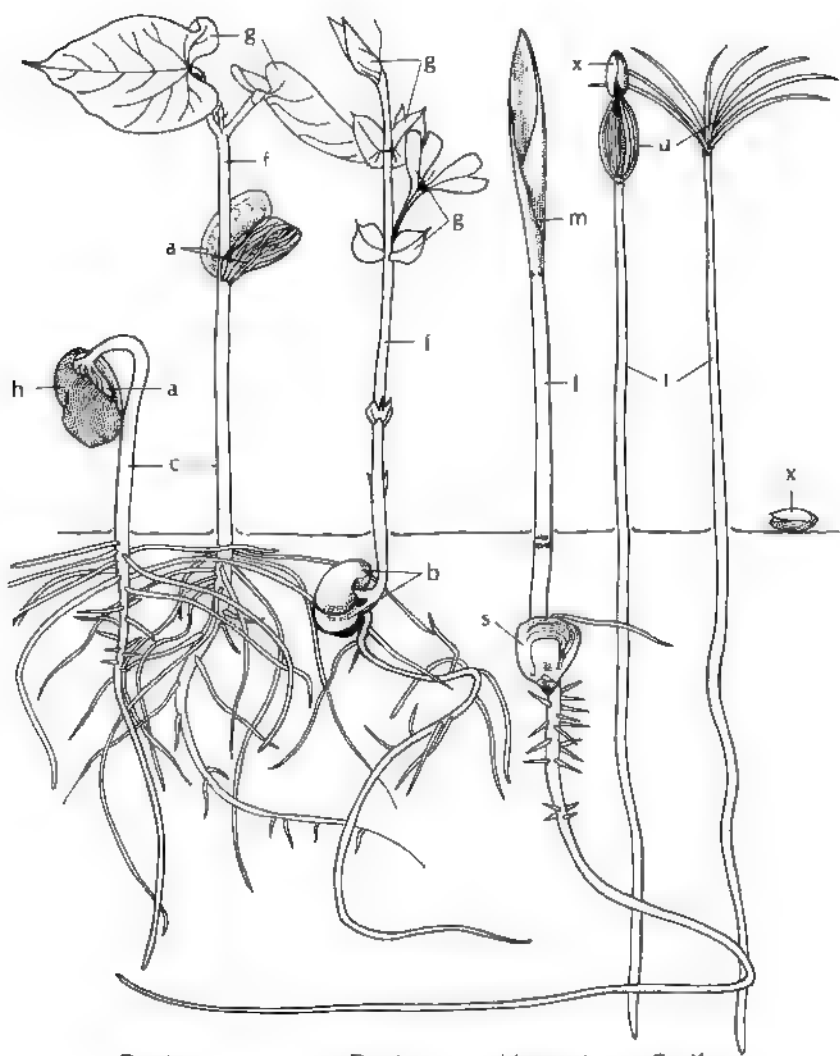


Monocot
Zea
Corn
× 5



Conifer
Pinus
Pine
× 8

Seedlings



Dicot
Phaseolus
Bean

Dicot
Pisum
Pea

Monocot
Zea
Corn

Conifer
Pinus
Pine

Major Groups; Geologic Time Scale

Learning about the relationships of plants to each other involves the study of plant fossils (paleobotany), physical characteristics (anatomy), form (morphology), inheritance (genetics), chemical characteristics (physiology and plant biochemistry), and plant communities (ecology).

Carolus Linnaeus (1707–1778) organized a system, that has since been expanded, for the classification of plants on the basis of their evolutionary relationships. Some groups of organisms studied by botanists are now no longer recognized as plants, as for example, bacteria, blue-green algae, fungi, and lichens. They are studied by specialists on bacteria and blue-greens (microbiologists), green, red, and brown algae (algologists), fungi (mycologists), and lichens (lichenologists).

The **Bacterial Group** consists of bacteria, blue-greens and other microorganisms. In the past, blue-greens were grouped with algae. Now it is known that they are genetically more like bacteria. The cells of bacteria and blue-greens do not have organelles; instead, the cell membranes carry on many of the biological functions.

There is no membrane-bound nucleus in the cell. This is termed **prokaryotic** (pro = before, karyon = nucleus). Nuclear material consists of strands of DNA (deoxyribonucleic acid, a molecule that constitutes the genetic information of a cell). Fibrils of DNA in the central region of a bacterial cell are designated by the term **nucleoid**. Asexual reproduction occurs by cell division or budding. Sexual reproduction is a recombination of genetic material. Most are microorganisms, smaller than the **eukaryotic** cells (eu = true, karyon = cell) of the other three kingdoms.

Revision Group. Classification and relationships of molds, mildews, rusts, chytrids and allies, dinoflagellates, algal groups, and stoneworts and others are currently under revision.

A characteristic in common in this group is the presence of nuclei (eukaryotic) in the cells. Many obtain food

(organic carbon metabolites) by photosynthesis within cell organelles called **plastids**. A flagellum (whip) for locomotion or feeding is present in many members. Most require oxygen (aerobic). They are aquatic.

Fungi are organisms with nucleated cells (eukaryotic), that form resistant fungal spores, have cell walls composed of chitin, and do not have mobile cells at any stage. Fungi are found from the fossil record 450–500 million years ago (the Ordovician period).

Representative divisions in this book are black bread mold and allies, sac fungi, and club fungi. Lichen classification is a problem because lichens are an association of either a blue-green or a green alga with either a sac fungus or a club fungus. Lichens are included here with the fungi.

Plants represented here include liverworts, hornworts, mosses, whisk ferns, clubmosses, spikemosses and quillworts, horsetails, ferns, and plants bearing seeds. Seed-bearing plants include the gymnosperms (= naked seeds) and the angiosperms (= enclosed seeds).

Living gymnosperm groups are cycads, ginkgo, conifers, and gnetes. The angiosperm group consists of flowering plants. Characteristics of plants are covered in all three sections of the book.

Geologic Time Scale

Eras. The largest units of geologic time are known as eras; each encompasses millions of years. They are basically defined by biological events – the appearance or disappearance of major groups of organisms. These changes in biology are related to major geologic events. However, only the biologic changes are seen worldwide in the fossil record.

Periods. Each era is subdivided into periods, and the periods are broken down into epochs; again their separations are most commonly based on fossils.

Geologic Time Scale

Era	Period	Life
Precambrian	Precambrian	The first fossil organisms of bacteria and blue-greens are found in rocks over 3,000 million years old. The earliest eukaryotic cells (true nucleated cells) are found in rocks about 1,000 million years old. These fossils are rare.
	600 million years ago	Fossils of invertebrate marine animals are present.
Paleozoic (Old Life)	Cambrian	
	500	
	Ordovician	The oldest fossils of fungi are from 450 million years ago and algae fossils are common. Dinoflagellates are present.
	430	
	Silurian	Oldest fossils of land plants are present.
	400	
	Devonian	Land plants became abundant during the Devonian. Fossils of clubmosses, spikemosses, quillworts, giant horsetails, scouring rushes and ferns are found in this period.
	345	
	Mississippian	During the Carboniferous (Mississippian and Pennsylvanian periods), there were vast forests of trees and swamps preserved now as coal.
	310	
	Pennsylvanian	
	280	
	Permian	During the Permian, gnetes were present and true conifers emerged. Ginkgos also originated during this period.
	225	
Mesozoic (Middle Life)	Triassic	The Triassic was the time of reptiles and dinosaurs and the first mammals. There were forests of gymnosperms and ferns. Cycads were also present.
	180	
	Jurassic	The Jurassic was the "age of cycads" and it was a time when conifers were distributed worldwide. Birds originated during this period. Reptiles were also dominant.
	136	
	Cretaceous	Primitive flowering plants evolved during the Cretaceous.
	65	
Cenozoic (New Life)	Tertiary	During the Tertiary, flowering plants dominated the land. Later, grasslands were apparent. The landscape has been dominated by herbaceous flowering plants ever since.
	2.5	
	Quaternary	Humans are present.

Fossils

Fossil Record and Appearance of Vascular Plants

About 85% of earth's geologic time is within the Precambrian. In the Precambrian, in rocks over 3,000 million years old, the first fossil organisms of bacteria and blue-greens are found. The earliest eukaryotic cells are from rocks about 1,000 million years old. These fossils are rare, and the early evolutionary history of non-vascular plants is obscure.

The division that marks the end of Precambrian time and the beginning of the Paleozoic, about 600 million years ago, is recognized by the worldwide appearance of fossils of invertebrate marine animals. In the late Silurian period, the first vascular plants appear. Vascular plants are so designated because they possess specialized conducting tissues of xylem and phloem (see 9).

Land plants became abundant during the Devonian. During the Carboniferous (Mississippian and Pennsylvanian), there were vast forests of trees and swamps preserved as what we know as coal.

The Jurassic time of the Mesozoic was the "age of cycads" and it was a time when conifers became distributed worldwide.

Primitive flowering plants evolved during the Cretaceous, and by the Tertiary time of the Cenozoic, they dominated the land. Later, grasslands were apparent and the landscape has been dominated by herbaceous flowering plants ever since.

Fossil Evidence. A fossil represents evidence of past life. Fossils are usually found in nature as preserved remains or they may be just an imprint of an organism or part of an organism. Usually, vascular plant fossils occur as fragments. They often show alteration of original structures through damage by transport away from where they lived and when rock deposits were formed.

During the process of fossil formation, plant parts commonly were compressed in soft sediment, which later hardened into rock, leaving an imprint such as a fern leaf. Or the plant was embedded in a soft matrix and later decayed as the rock formed, leaving a mold of its exterior. Or later, a hollow mold may have been filled in with mineral deposits forming a natural cast of the plant structure.

Embedded, "**petrified**" plant fossils are a result of cell contents being replaced by minerals while the cell walls are preserved. Thus, thinly cut sections reveal the microstructure of the fossilized plant parts.

Paleobotany. This is the study of fossilized plants. As parts of plants are found, they are given "form genus" names. For example, a stem section, a leaf, a root, or a reproductive part such as a seed may all have different names, even after it is assumed that all belong to one extinct plant. An illustration of an entire fossil plant is a graphic reconstruction based on fossilized parts found.

Of interest . . . **organic evolution:** origins and relationships or past and present life forms are better understood from their fossil record. By determining the ages of rock formations, it can be determined when plants first appeared and when they became extinct or yet survive.

Economic: Coal deposits result from peat beds of decaying plants; an example is coal formed during the Carboniferous (Mississippian and Pennsylvanian). The term "carboniferous" is often used to refer to the two Paleozoic periods because of the extensive coal beds formed then. Pressure and heat from overlying rock sedimentation over millions of years compressed and converted the peat into coal. One of the methods for finding oil is the study of samples, obtained from drill holes, of microfossils of specific plants, pollen grains, and animals.

Paleogeography. By studying the distribution of certain fossils over the earth's crust, it is possible to determine ancient relationships of lands and seas.

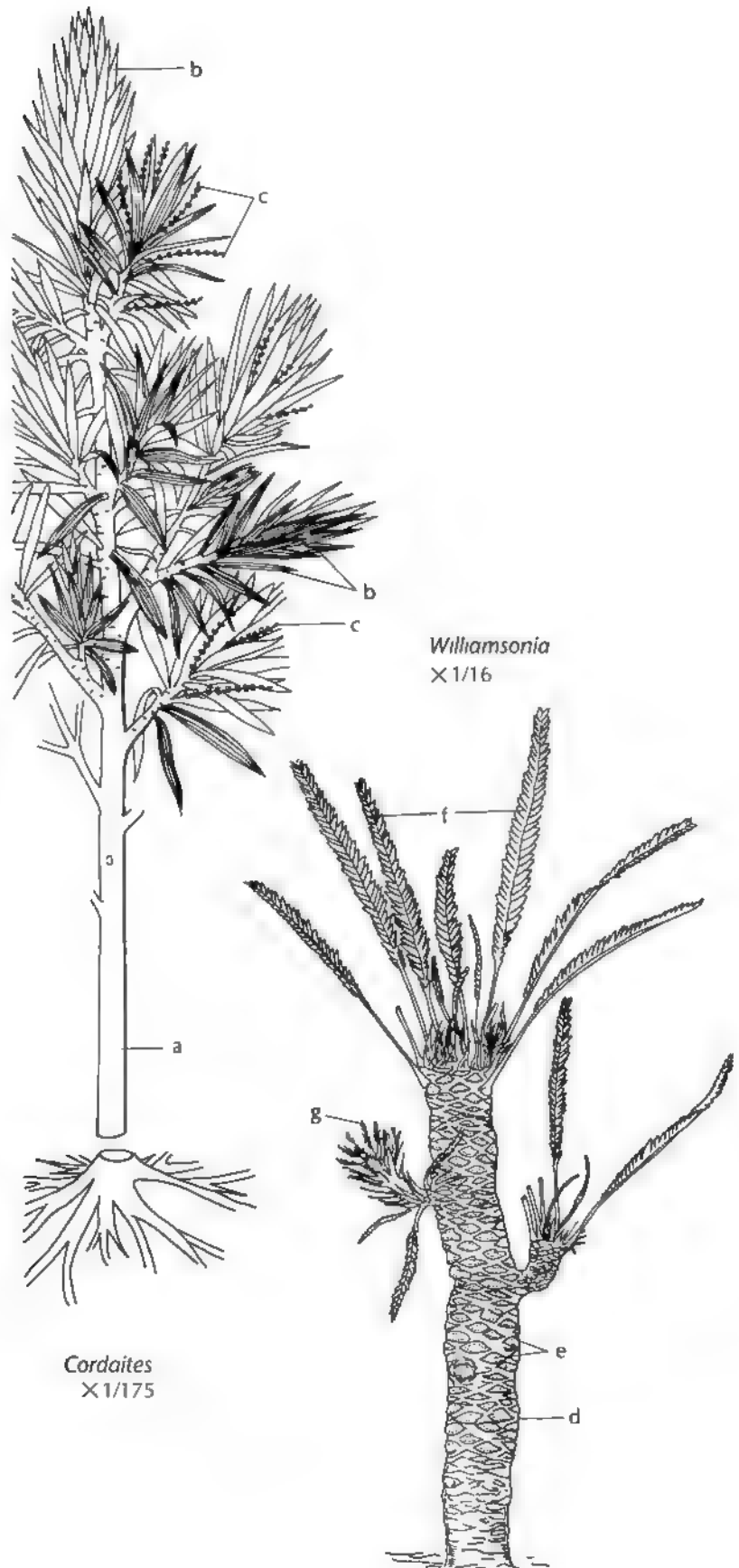
Paleoecology. Fossil organisms found together indicate ancient relationships, environment and climate.

Cordaites

This conifer-like tree, which reached about 30 meters in height, was prominent during the Carboniferous. Its trunk (a) was woody; the strap-shaped, or sometimes fan-shaped, leaves (b) had parallel veins that branched dichotomously from the base. The leaves were up to a meter long. Reproductive structures (c) that resembled cones on an axis, bore male pollen sacs or female cone scales with ovules that developed into winged seeds after fertilization. (drawing after Grand'Eury, M. F. Cyrille, 1877)

Williamsonia

Cycadoid plants evolved in the late Carboniferous and became extinct during the late Cretaceous. One of these, *Williamsonia*, reached a height of 2 meters. The plant had a columnar trunk (d) marked with old leaf base scars (e) and whorls of leafy fronds (f) similar to living cycads, although not related. Male pollen sacs and a female seed-bearing organ were borne in a flower-like structure (g). (drawing after Sahni, 1932, Geologic Survey of India)



COLOR CODE

tan: trunk (a, d)
green: leaves (b, f)
yellow: reproductive structures (c, g)
brown: leaf base scars (e)

Fossils (continued)

Rhynia

This plant lived only during the Devonian. *Psilotum* (see 64) and *Tmesipteris* are living plants that resemble *Rhynia* but are not known in the fossil record. *Rhynia* had simple hair-like rhizoids (a), a creeping underground stem (rhizome, b) that gave rise to upright, branching shoots (c) that reached 50 cm in height. As there were no leaves, it is assumed photosynthesis took place in the green stems. Spore cases (sporangia, d) containing spores were borne at the shoot tips. (drawing after Hirmer, 1927, R. Oldenbourg)

Lepidodendron

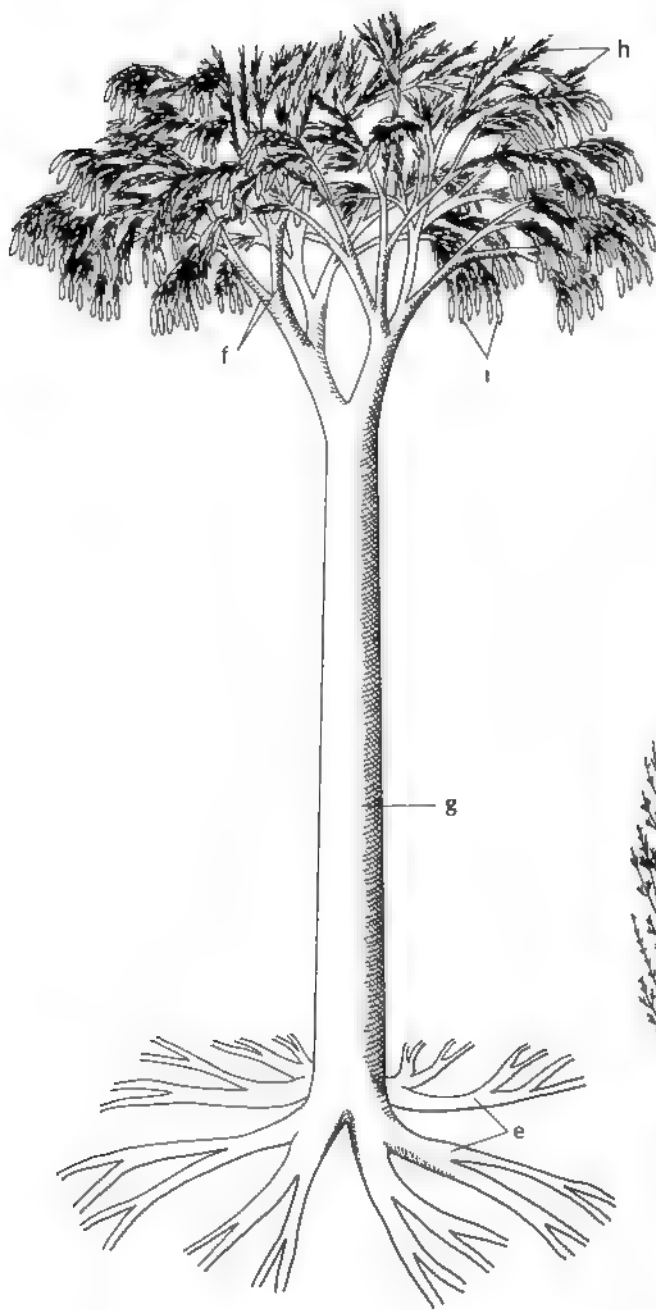
This tree reached 30 meters in height and was abundant during the Carboniferous. It is related to living lycopods (see 65). The stem bases (e) and stems (f) were dichotomously branched (fork of two branches of equal length). Diamond-shape leaf scars covered the outer surface of the upright stem (g) and upper branched stems. Extending beyond the leaves (h), cones (i) of sporangia with two kinds of spores (heterosporous condition) grew at the tips of stems. (drawing after Hirmer, 1927, R. Oldenbourg)

Calamites

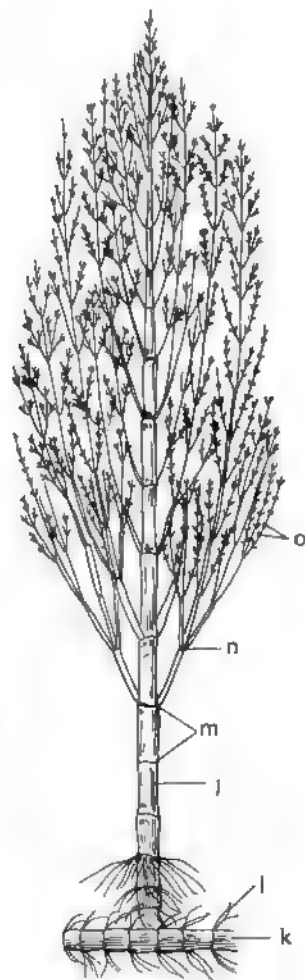
A tree that had secondary growth and thick bark, *Calamites* reached 10 meters in height. Although much smaller and herbaceous, living *Equisetum* (see 66) plants greatly resemble this ancient relative that lived during the Devonian and Mississippian periods. The upright stem (j) arose from an underground rhizome (k) and possessed roots (l) at the nodes. Stem nodes (m) bore whorls of stems (n). Stem ends had whorls of needle-like leaves (o). (drawing after Hirmer, 1927, R. Oldenbourg)

COLOR CODE

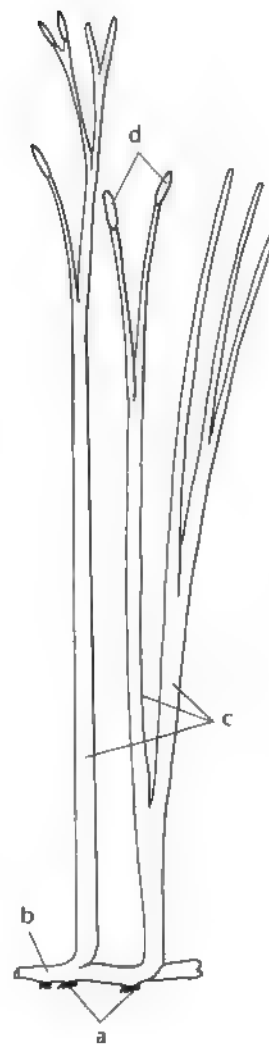
white: rhizoids (a), rhizome (b, k)
green: shoots (c), leaves (h, o), stem (j),
whorls of stems (n)
brown: sporangium (d)
tan: stem bases (e), branched stems (f),
upright stem (g), cones (i)



Lepidodendron
× 1/90



Calamites
× 1/85



Rhynia
× 1/3

Blue-greens

Fossil history of the blue-greens extends back to the Precambrian. They are found in water, in and on soil, on rocks, and in the atmosphere. Habitat temperatures range from 0° to 85°C. Some species occur in lichens, liverworts, water ferns, cycads, and flowering plants as symbionts (dissimilar organisms that live together and may, or may not, be beneficial to each other).

Characteristics. The microscopic blue-greens have no membrane-bounded nucleus (prokaryotic, pro = before). [All plants and animals have membrane-bound cell organelles including nuclei (eukaryotic, eu = true).] The cell has a mucilaginous sheath of pectin that surrounds the cell wall and an inner cellulose wall.

Cell contents (protoplasm) include nuclear material with DNA fibrils, chlorophyll a, and accessory pigments of blue (phycocyanins), red (phycoerythrin), orange (carotenes), and xanthophylls (yellow) colors. These pigments are involved in capture of light and subsequent formation of carbohydrates (photosynthesis). Cyanophycean starch is the storage product.

Blue-green forms may be one cell (unicellular), colonial (cells held together by a gelatinous sheath), or filamentous (chains of cells called trichomes). They have no thread-like structures (flagella) for movement.

Reproduction. Blue-greens have no known sexual reproduction. Reproduction of unicellular forms is by cell division in which the cell wall folds in and “pinches” the cell into two cells. Colonial and filamentous forms fragment into separate pieces. Filamentous forms have various specialized cells: an **akinetete** is a resistant cell filled with food reserves, which can germinate to form a new filament; a transparent **heterocyst** functions in nitrogen-fixation, and frequently is located where the filament breaks. Some genera have **exospores**. These are cells that pinch off the filament.

Of interest . . . **ecosystem:** blue-greens are primary colonizers on bare soil and rock; by forming mats that bind to the soil surface, they reduce soil erosion. As

nitrogen-fixers, they contribute to soil fertility (e.g., growing in rice paddies, *Anabaena*, in association with the floating water fern, *Azolla*, see 70, increases rice production). Blue-greens contribute to the water plankton **food chain**; **reef building**, in tropical waters blue-greens precipitate calcium carbonate (limestone) out of water and build up rock layers; **toxins:** “blooms” of dense concentrations in the sea kill marine fish, and in reservoirs, they may cause gastrointestinal diseases in cattle and humans.

Synechococcus

Structures of this unicellular spherical (coccoid) blue-green include a mucilaginous sheath (a), cell wall (b), plasma membrane (c) and protoplasm (d). Reproduction is by **binary fission** (splitting into two).

Cylindrospermum

This filamentous blue-green has an akinete (resistant cell, e) and a heterocyst (spore-like cell, f) at the end of the trichome.

Anabaena

A heterocyst (g) is located near the center of the trichome. This filamentous genus is a frequent part of water “blooms.” In reservoirs it can cause bad odor and taste to water, killing birds and animals with endotoxin (released on decomposition).

Gloeotrichia

Colonies of trichomes are formed. The tapered trichome has a heterocyst (h) and an adjacent akinete (i).

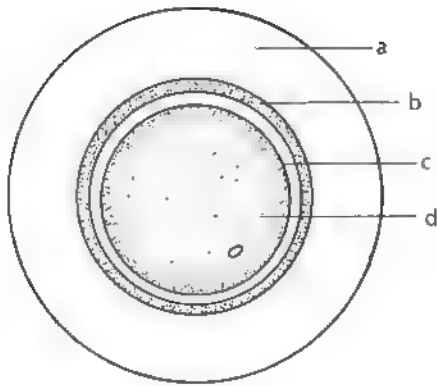
Hapalosiphon

The trichome is branched, with a heterocyst (j) present. Branches form as the cells divide on a perpendicular plane.

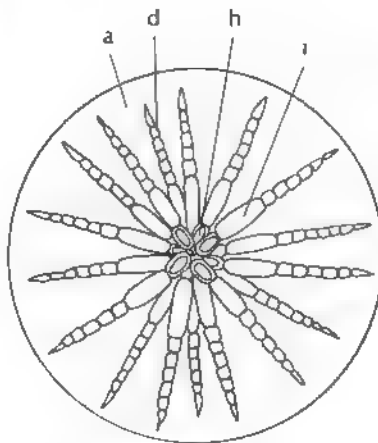
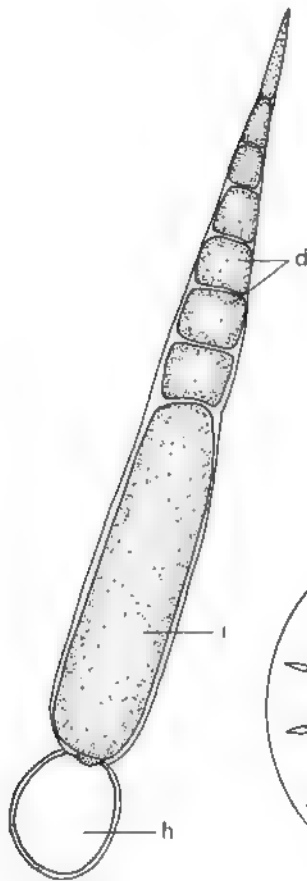
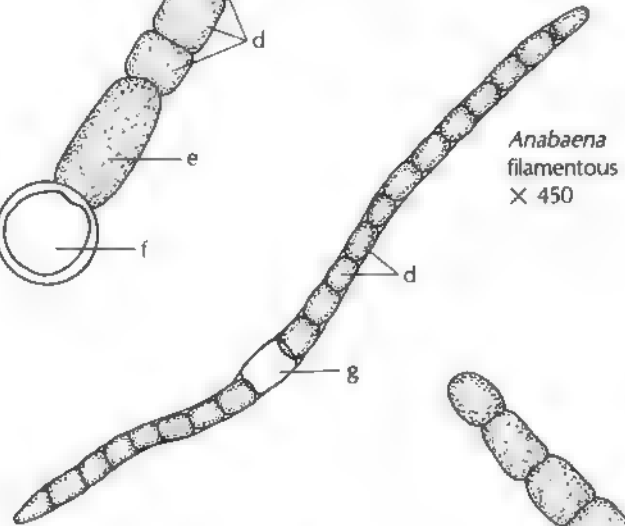
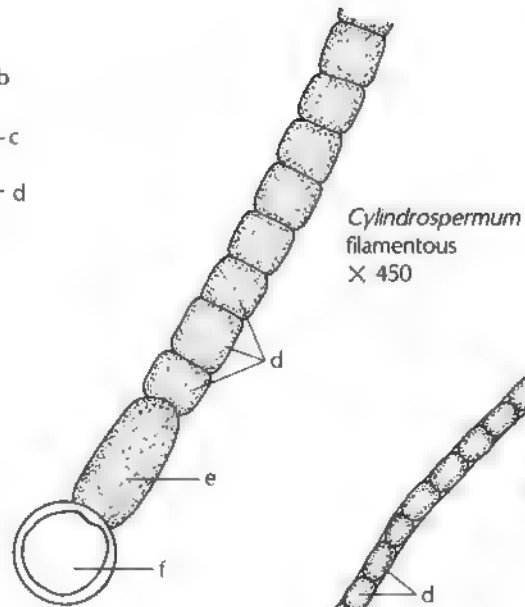
COLOR CODE

white:	sheath (a), heterocyst (f, g, h, j)
tan:	wall (b)
blue-green:	protoplasm (d)
dark blue-green:	akinetete (e, i)

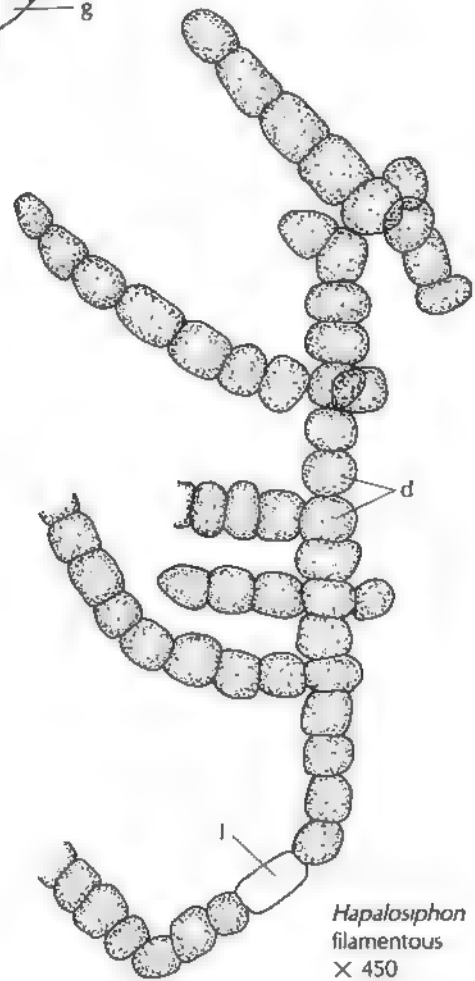
Blue-green Forms



Synechococcus
unicellular
diagram of structures



Gloeotrichia
diagram of colony



Slime Molds

Even when organisms were grouped as either plants or animals, no one knew what to do with the slime molds. The creeping acellular phase is animal-like, while the reproductive structures that produce spores are plant-like. Now, true slime molds are recognized as a separate taxonomic group.

Characteristics. There are about 450 species of slime molds distributed worldwide. Most live in shady moist woods on decaying wood, leaves, or moss. Some occur in open, but moist areas, such as lawn grass. They can be found, also, on damp bark mulch used in gardens.

Their diet is bacteria, protozoa, fungal spores, and other minute organisms. The body of a slime mold is called a **plasmodium** (a), consisting of a membrane covering without cell walls, and containing many nuclei. Some plasmodia move in an amoeba-like fashion, flowing over surfaces, engulfing nutrients and other food sources.

When temperature or moisture conditions are unfavorable, the plasmodium may convert to a hardened mass in a resting dormant condition called a **sclerotium** (b). Or with a temporarily dry environment, the plasmodium may mature to the fruiting stage.

In the spring in north temperate regions slime molds can be found on wet rotting logs and examined with a hand lens. Throughout the summer, various forms of fruiting bodies can be discovered, such as those shown here.

Reproduction. The life cycle consists of the plasmodium fusing with other plasmodia, increasing the number of nuclei, which divide simultaneously; engulfing food; and eventually, converting into fruiting bodies called **fructifications**. The three types of fructifications formed by various species are sporangia, aethalia, and plasmodiocarps.

A **sporangium** may have a stalk (h) or not, with a base called a **hypothallus** (i), and a wall of varying lime content, the **peridium** (g), that encloses the spores. Inside the peridium may be a non-living network of hairs, **capillitium** (f), that aid in spore dispersal.

An **aethalium** is cushion-shaped with a peridium (o) enclosing the spores, such as *Lycogala* shown here.

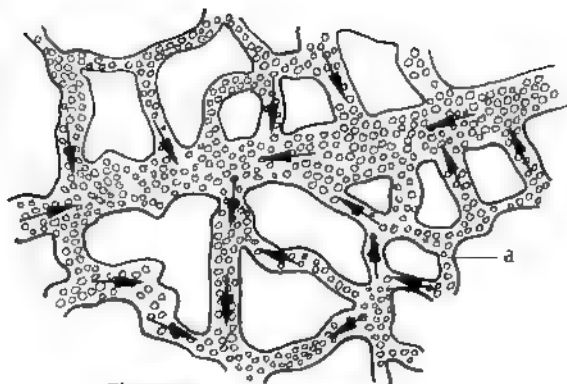
The third type of fructification is a **plasmodiocarp**, which retains the net-shape of the plasmodium.

By reduction division (meiosis), 1n spores are produced. With favorable environmental conditions, the spore germinates into a myxamoeba without **flagella** (flagella, pl.; flagellum, sing. = whip-like structure for movement) or a swarm cell with flagella. These cells function as sex cells (gametes). Two cells fuse to form a 2n zygote nucleus, which divides mitotically to develop into a plasmodium.

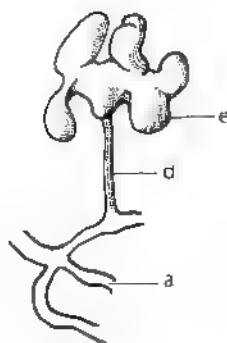
Of interest...**blue lawn infestation:** *Physarum cinereum*; **research material:** slime molds provide pure, cell-less protoplasm for genetic, developmental, and cancer studies; **ecosystem:** primary decomposers in the forest food chain.

COLOR CODE

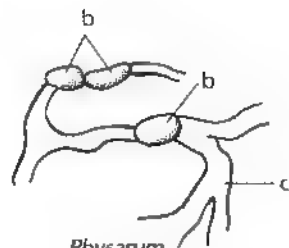
yellow:	plasmodium (a), sclerotia (b)
yellow-brown:	dried plasmodium (c), capillitium (f)
gray:	stalk(d), peridium (e)
tan:	peridium (g), wood (y)
dark brown:	stalk (h), hypothallus (i)
brown:	spores (j)
black:	stalk (k)
white:	lime dots on peridium (l), hypothallus (v), stalk (w)
dark brown:	peridium (z, p), stalk (m, q)
green:	moss (n)
pink:	peridium (o)
orange-brown:	hypothallus (r), stalk (s), peridium(t),capillitium(u)
iridescent (dots of green, red, yellow):	peridium (x)
orange:	plasmodiocarp



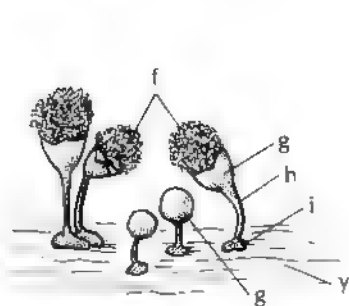
Physarum
plasmodium
arrows indicate protoplasmic flow
magnified



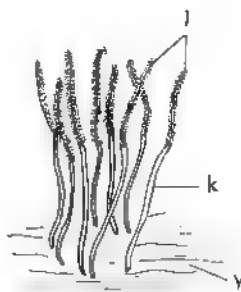
Physarum
sporangium
× 10



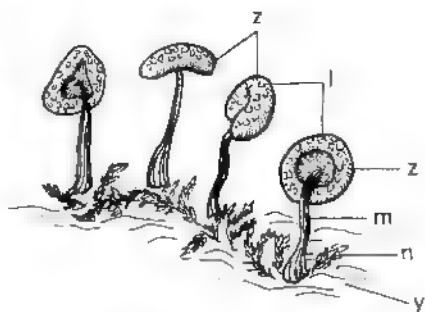
Physarum
sclerotia
× 10



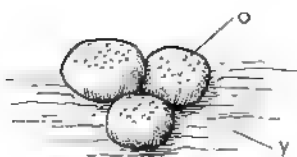
Hemitrachia
sporangia
× 10



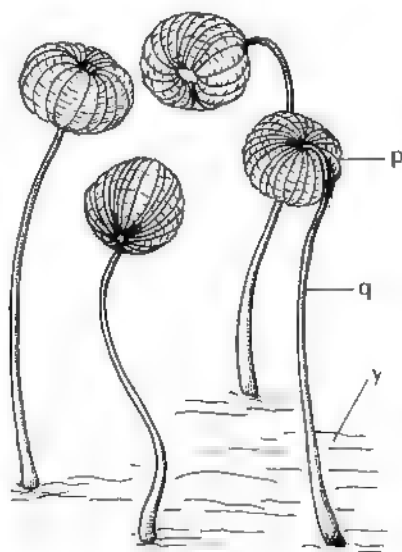
Stereocarpus
sporangia
× 3



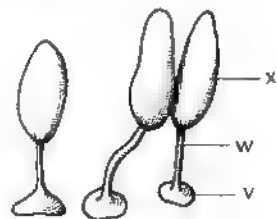
Didymium
sporangia
× 10



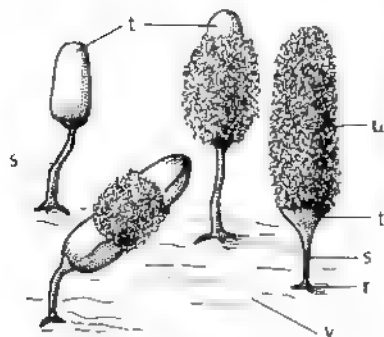
Lycogala
aethelia
× 2



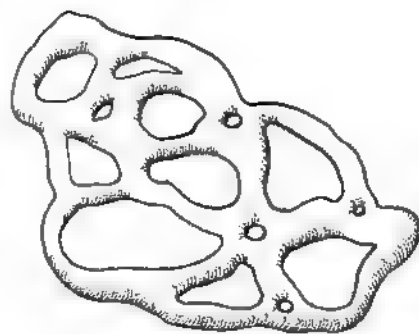
Dictydium
sporangia
× 20



Diachea
sporangia
× 10



Arcyria
sporangia
× 10



Hemitrachia
plasmodiocarp
× 10

Water Molds, Downy Mildews, White Rusts

In this Oomycete group, organisms are microscopic and found in water and moist soil. The most advanced forms live entirely within a plant or animal host. They range from one cell to copious amounts of threadlike strands. Each strand of a threadlike tubular filament is called a **hypha** (pl. hyphae). A mass of hyphae is called **mycelium**. The cell wall contains cellulose.

Reproduction is by oospores, sexually produced, non-motile cells; and, asexually, by zoospores with two unlike flagella that are used for motility.

Of interest... *Albugo* spp. (causes white rust of horseradish, cabbage, sweet potato, morning glory, spinach), *Aphanomyces* (causes root disease of sugar beets, peas), *Phytophthora infestans* (causes late blight of potato), *Phytophthora ramorum* (causes sudden oak death), *Plasmopara viticola* (causes downy mildew of grapes), *Pythium debaryanum* (causes damping-off of seedlings), *Saprolegnia* (causes disease of fish eggs and fish).

Achlya

The water mold illustrated here has separate male and female individuals. Eggs (a) are produced in an egg chamber (oogonium, b) on the hypha (c). From a male individual, antheridia (d) with male gametes branch from a hypha (e). After fertilization by a male gamete from the antheridium, an egg develops into a 2n oospore (f). The oospore germinates to form a new body of hyphal strands (g) that produces biflagellated zoospores (h).

Chytrids and Allies

The Chytridiomycetes are simple, microscopic organisms that live in both water and soil. They may be a single cell living within the cell of a host alga or higher plant or have true mycelia and live on the surface of a host. The motile cells have one whiplash flagellum. The cell walls of chytrids are made up of chitin, a tough resistant carbohydrate. Some have cellulose in their cell walls also.

Of interest... Some chytrid parasites destroy algae. Some are parasitic on economic plants that include *Physoderma* (causes brown spot of corn), *Synchytrium* (causes black wart disease of potato tubers), and *Urophlyctis* (causes crown wart of alfalfa).

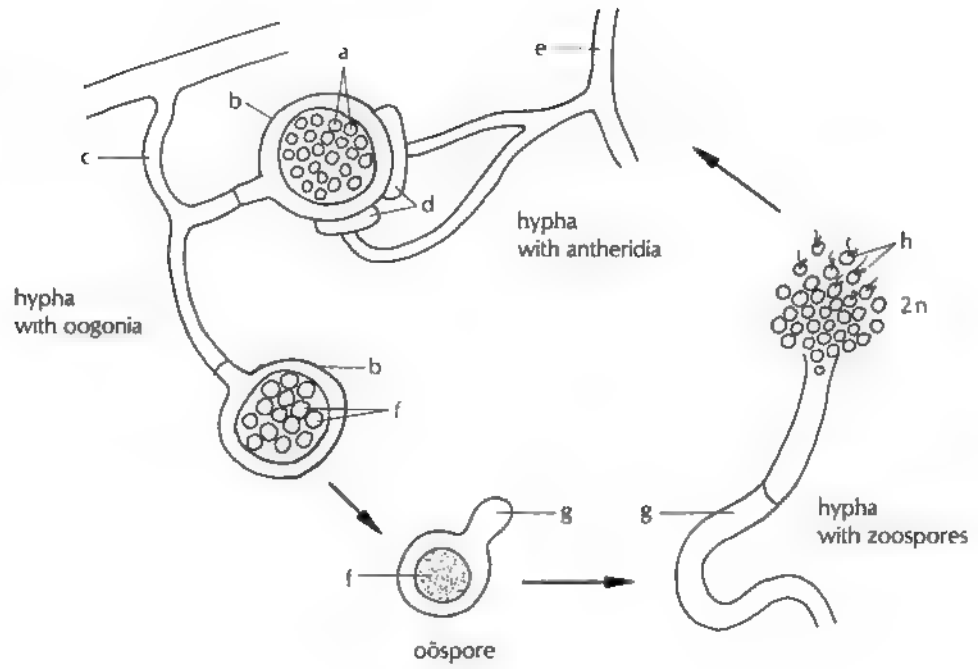
Allomyces

The 2n mycelium of this chytrid produces thin-walled spore-bearing structures called **sporangia** on hyphal strands (i). From a sporangium (j), 2n spores (k) emerge. Other, thick-walled sporangia (l) produce 1n spores (m) by **meiosis** (nuclear divisions that reduce the number of chromosomes by half). A 1n spore germinates into a 1n hypha (n), which produces 1n sex cells (gametes, o, p) in gametangia (q). Fusion of unlike gametes into a zygote (r) results in the germination of spore-bearing hyphae (i).

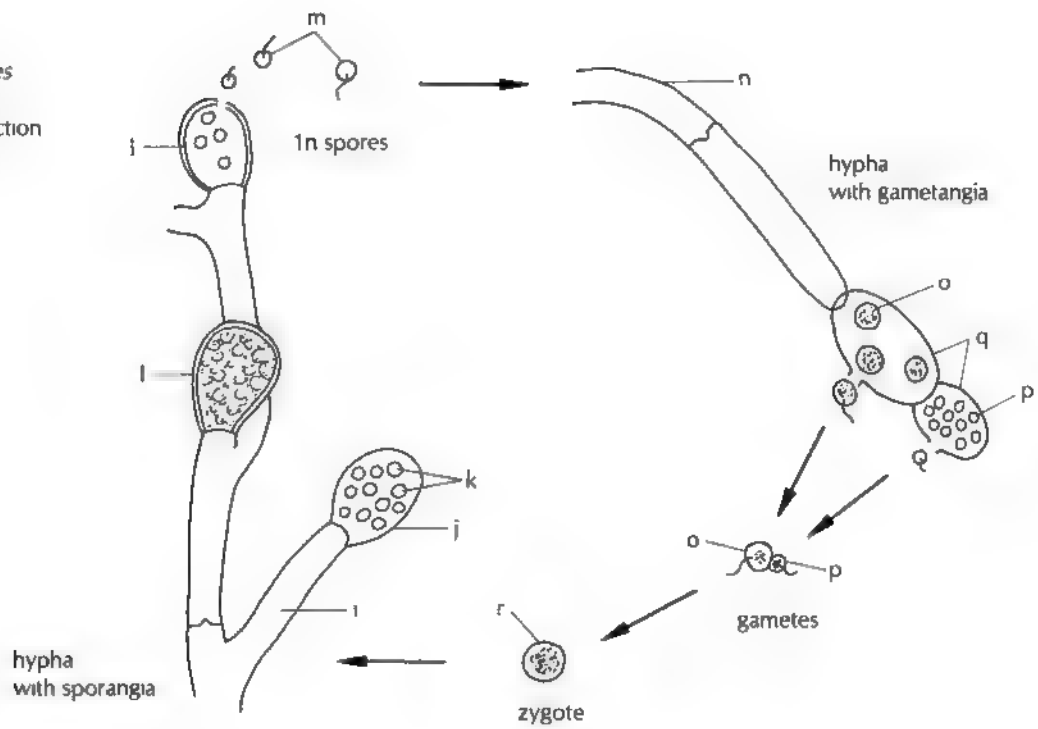
COLOR CODE

optional: egg (a) gamete (o, p), antheridia (d),
oospore (f), zygote (r)
gray: oogonium (b), hypha (c, e, g, i, n)
yellow: zoospores (h, k, m)
colorless: sporangium (j, l), gametangia (q)

Achlya
Water Mold
reproduction



Allomyces
Chytrid
reproduction



Fungi

Characteristics: Fungi are organisms without chlorophyll, and therefore, are dependent on other organisms for nutrition. A **saprophytic** fungus obtains food from dead organic matter. A **parasitic** fungus feeds upon a living organism, the host. **Symbiotic** fungi live in a mutually beneficial relationship with a host. A fungus associated with roots of a higher plant, called a **mycorrhizal** association, may be parasitic or symbiotic. In a symbiotic relationship both the plant and the fungus benefit. The fungal associate on plant roots produces digestive **enzymes** (proteases/peptidases) that release amino acids from proteins and absorb extra amounts of phosphorus from the soil, thence to the plant. The fungus benefits by using carbon—basal metabolites (e.g., sugars, amino acids, vitamins) from the plant roots.

Carl Zimmer reported in 1997 that Suzanne Simard, a forest ecologist, discovered a fungal mycelium connected to several trees and even trees of different species. A forest community of plants can be ecologically interconnected to the point where removal of so-called weed trees disrupts the survival of the entire group of plants. She concluded that the fungus extracted carbon from healthy trees and shared it with trees growing under unfavorable light conditions. It is thus important to maintain diversity in forests for the health of all the plants.

Fungi range in size from one-celled, microscopic organisms to masses of cells strung together in long filamentous strands. Each strand is called a **hypha**. The mass of hyphae that make up a fungal body is called **mycelium**. Cell walls are made up of chitin, which is hard and resists water loss.

Reproduction. All fungi bear spores that germinate into strands of hyphae. The microscopic lower fungi mainly live within a host and reproduce mostly by asexual spores. Higher fungi have elaborate fruiting bodies, composed of hyphae, in which spores are produced. Sexual reproduction, used as the basis of fungal classification, commonly occurs once a year.

Black Bread Mold and Allies

Their sexual resting spores (zygospores) define zygomycete fungi. Another characteristic is the asexual, non-motile, reproductive spore. Of interest . . . *Rhizopus stolonifer* (causes black bread mold, strawberry leak,

and sweet rot of potatoes), *Choanephora cucurbitarium* (causes squash flower and fruit mold); *Absidia* sp., *Mucor* spp., *Rhizopus* sp. (can be fatal to the human nervous system).

Mucor

Hyphae (a) of compatible mating types develop side branches (b) that meet. A swelling or progametangium (c) is produced at each side. The walls (d) between the two break down. The nuclei from each progametangium fuse together and form a zygospore (e) that is held by suspensors (f).

Sac Fungi

Ascomycete fungi sexually produce usually 4 or 8 ascospores (g) within a sac sporangium called an **ascus** (h). Asexual reproduction occurs by breaking off (fragmentation) of mycelium, by splitting of one cell into two cells (fission), by budding of cells, and by formation of conidia. Fungi in the Hemiascomycetidae have little or no mycelia and the asci are not produced in a spore-bearing structure or fruiting body. Yeasts have evolved from several evolutionary lines, but are grouped together for convenience. They are found in sugary substances such as flower nectar and on the surface of fruits, in soil, in animal wastes, in milk, and in other substances. They have the ability to ferment carbohydrates, producing alcohol and carbon dioxide, as in wine and beer making. The leaf curl disease-causing fungi are classified with the yeasts, as both may form buds on the **ascospores**. Of interest . . . *Saccharomyces cerevisiae* (baker's and brewer's yeast), *Taphrina* spp. (causes leaf curl or peach, chokecherry, oak, witch's broom of cherries).

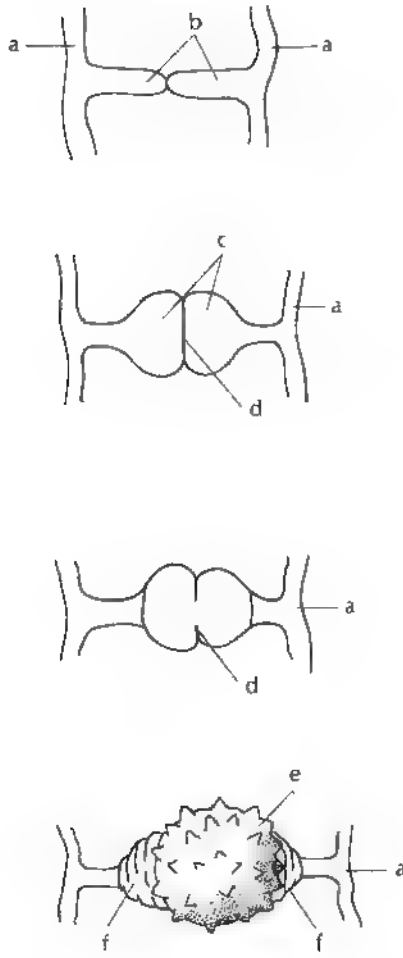
Saccharomyces cerevisiae Yeast

Yeasts are microscopic, unicellular organisms (i). Asexual reproduction occurs by cell division and budding (j). Sexual reproduction, while rare, is by fusion of two cells to form an ascus (k) with 4 ascospores (l).

Taphrina deformans Peach Leaf Curl

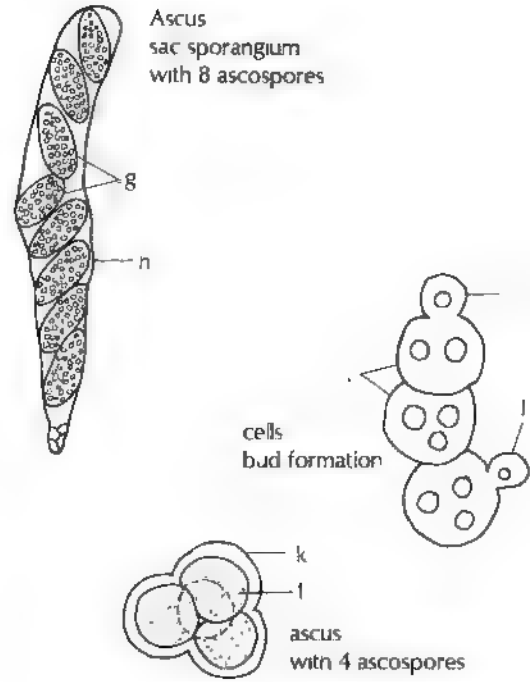
Budding spores infect the peach leaf (m) producing more buds or mycelia, which penetrate the leaf tissue. The host tissue reacts to this infection by forming swollen, tumor-like masses (n) and by tortuous curling of the leaves.

Lower Fungi

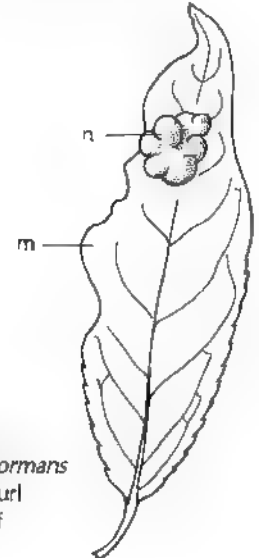


Mucor
zygospore formation

Sac Fungi



Saccharomyces cerevisiae
Yeast



Typhrina deformans
Peach Leaf Curl
on peach leaf
 $\times 1$

COLOR CODE

gray:	hypha (a), tips (b), progametangium (c), zygospore (e), suspensors (f)
yellow:	ascospore (g, l)
beige:	cell (i, j)
colorless:	ascus (h, k)
brown:	masses (n)
green:	leaf (m)

Molds, Mildews, Morels (Sac Fungi)

Usually members of this Euscomycetidae group have asci (sac sporangia) enclosed in a fruiting body called an **ascocarp**. A cleistothecium, a perithecium, and an apothecium are types of ascocarps. A **cleistothecium** (c) is an enclosed ascocarp composed of loose masses of hyphae with asci irregularly arranged within. A **perithecium** (h) is a vase-shaped ascocarp with a pore (ostiole, i) at the top. It may be embedded in a compacted mycelial structure (stroma, j). An **apothecium** is a cup-shaped ascocarp with asci lining the open surface (see 54, *Xanthora*, j).

Of interest...**molds:** *Aspergillus* spp. (mold on bread, leather; causes human skin and respiratory disease), *Aspergillus oryzae* is used to make sake from rice in Japan, *Claviceps purpurea* (ergot of rye), *Neurospora* (pink bread mold), *Penicillium italicum* (blue mold on citrus fruits and preserves), *P. digitatum* (green mold on citrus fruits), *P. camemberti* (flavoring in Camembert cheese), *P. roqueforti* (for flavor in production of Roquefort cheese), *P. notatum* and *P. chrysogenum* (source of the antibiotic, penicillin); *Rhizopus nigricans* (black bread mold); **wilts:** *Ceratocystis* spp. (oak wilt, Dutch elm disease); **blight:** *Endothia parasitica* (chestnut blight); **powdery mildews:** *Chaetomium* (of clothes), *Podosphaera leucotricha* (of apple), *Sphaerotheca pannosa* (of roses); **rot:** *Monilinia fructicola* (brown rot of stone fruits such as peach, plum, cherry, apricot); **wild:** *Helvella* and *Gyromitra* (false morels), *Morchella* (morel), *Tuber maganatum* (white truffle), *T. melanosporum* (black Perigord truffle), *Verpa* (bell morel).

Truffles form a mycorrhizal association with roots of oak, hazel, poplar and many other trees. Of the 200 species, two edible species are found in France and Italy. Hunters using trained pigs and dogs gather them. Small mammals (chipmunks, voles and squirrels) feed on truffles and disperse fungal spores in their fecal matter.

Penicillium

Asexual reproduction occurs by microscopic spores called **conidia** (a) formed on the side of a hyphal strand (b). By subjecting conidia of *Penicillium chrysogenum* to ultra-violet irradiation, surviving colonies have a high yield for penicillin production. It is a naturally occurring antibiotic. Discovery came when it was observed that

in Petri dishes, bacterial colonies died when "contaminated" with *Penicillium*.

Microsphaera alni Powdery Mildew of Lilac

The microscopic fruiting body is a cleistothecium. The wall (c) has been broken to reveal 2 asci (d) with ascospores (e). Appendages (f) aid in spore dispersal.

Diatrypella

In this fruiting body, asci (g) line perithecia (h) with terminal pores (i). They are embedded in a hyphal stroma (j).

Morchella Morel

Easily recognized, this edible mushroom is prized for its distinctive flavor. Apothecia with asci line the cavities (k) of the spongy-looking fruiting body. In spring, morels are a mushroom hunter's favorite find in northern deciduous wooded areas.

Claviceps purpurea Ergot of Rye

An ascospore germinates to form a mat of mycelium on a rye flower (see 123). Instead of a rye grain (m) developing, the fungal mycelium forms an overwintering asexual mass—a dark, hardened **sclerotium** (n). This sclerotium contains ergot alkaloids that poison cattle when grazing and humans when eating contaminated rye flour products. Also in humans, ergot causes gangrene.

Xylaria Dead Man' Finger

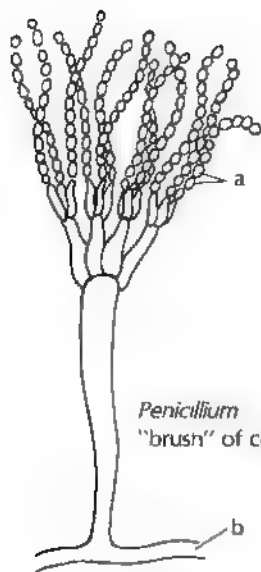
Perithecia are embedded in the outer wall of the stroma (o) or "finger," which develops on rotten, burned wood. Mycelial filaments (p) are shown.

Daldinia concentrica

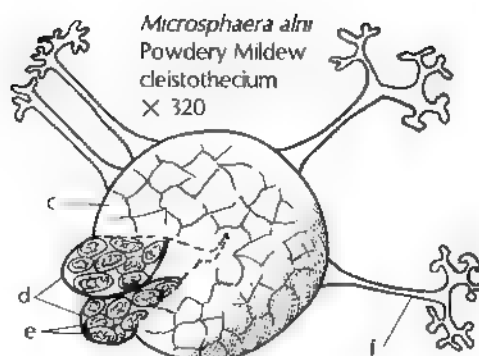
A vertical section reveals perithecia (q) lining the outer stromatic surface (r) of this cushion-shaped fruiting body.

Geoglossum difforme, *Microglossum rufum* Earth Tongues

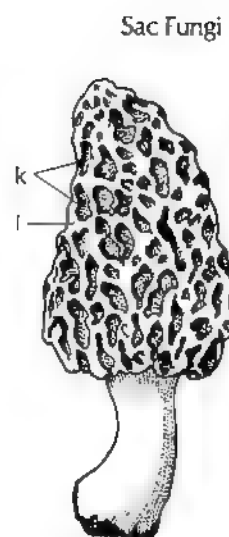
Apothecia of asci form on the surface of the club-shaped fruiting bodies (s, t).



Penicillium
"brush" of conidia



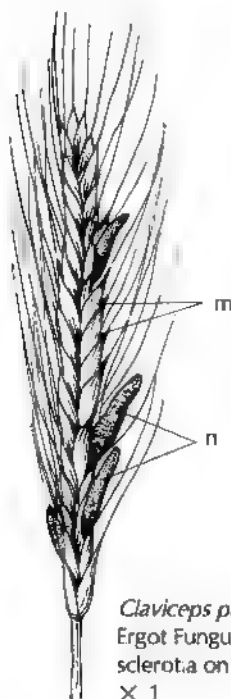
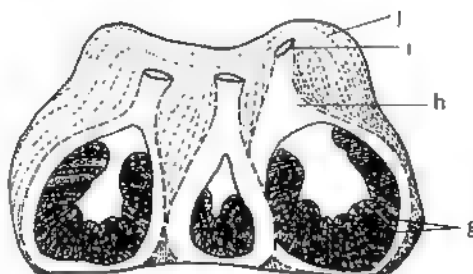
Microsphaera alni
Powdery Mildew
cleistothecium
× 320



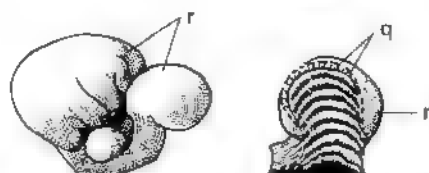
Sac Fungi

Morchella
Morel
fruiting body
× 1

Diatrypella
fruiting body
vertical section
× 90

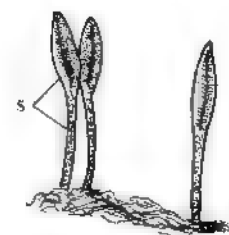
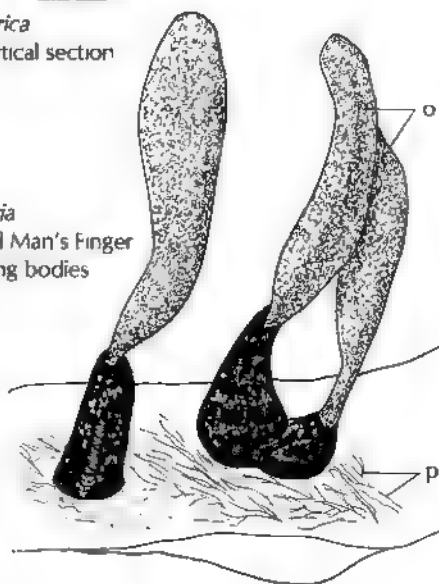


Claviceps purpurea
Ergot Fungus
sclerotia on rye
× 1

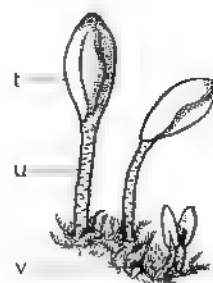


Daldinia concentrica
fruiting body, vertical section
× 1

Xylaria
Dead Man's Finger
fruiting bodies
× 1



Geoglossum difforme
Smooth Earth Tongue
fruiting bodies
× 1



Microglossum rufum
Earth Tongue
fruiting bodies
× 1

COLOR CODE

yellow:	conidia (a), ascospore (e), ascus (g)
colorless:	ascus (d), pores (i), filaments (p), perithecium (q)
gray:	hypha (b), perithecium (h), stroma (o)
black:	wall (c), stroma (j), fruiting body (s)
white:	appendages (f)
beige:	fruiting body (k, l)
gold:	grain (m)
dark brown:	sclerotium (n), stalk (u)
purple:	stroma (r)
orange-red:	fruiting body (t)
green:	moss (v)

Rusts, Smuts, Jelly Fungi (Club Fungi)

For club fungi sexual reproduction results in usually 4 basidiospores (a) produced on the outside of a microscopic club-shaped sporangium called a **basidium** (b). When basidia are borne in a fruiting body, it is called a **basidiocarp**. Familiar forms are mushrooms, shelf fungi and puffballs. Also included are rusts, smuts, jellies, stickhorns, bird's-nest fungi, coral fungi and earth stars. There are many edible species; however, there are no rules, only myths, for distinguishing poisonous from edible fungi. There are about 22,000 species of basidiomycetes.

Rusts (Uredinales). Fungi in this order are **obligate parasites** (require living hosts) on plants. No fruiting bodies are produced. Classification is based on the presence of teleutospores, representing the overwintering, resting stage. Many rusts attack only specific plants. Some require two hosts to complete their life cycles. For example, wheat rust alternates between wheat (*Triticum*) and barberry (*Berberis*)—unrelated hosts. This is called **heteroecism** (different homes).

Of interest... *Cronarium ribicola* (white pine blister rust with currants and gooseberries as the alternate hosts), *Gymnosporangium* spp. (rusts of juniper, apple, hawthorn, and pear), *Puccinia* spp. (rusts of wheat, barley, oats, rye, and hollyhock), *Uredinopsis osmundae* on alternate hosts of balsam fir (*Abies balsamea*) and cinnamon fern (*Osmunda cinnamomea*).

Gymnosporangium juniperi-virginianae

The life cycle of this fungus is completed by alternation of the fungus between apple (*Malus*) and red cedar (*Juniperus virginiana*) host plants. The cedar apple gall (c) is a mass of mycelium on cedars (d). During spring, gelatinous structures, telia (e), expand with water uptake (e.g., from rainfall) and protrude from the surface. Inside a telium are hundreds of teleutospores, basidial structures that produce basidiospores after germination on apple trees.

Smuts (Ustilaginales). Smuts form masses of black, sooty-looking teleutospores. Smuts are similar to rusts but do not need living host material and can be grown in the laboratory. Of interest... *Tilletia foetia* (bunt or stinking smut of wheat), *Ustilago* spp. (smut of corn, oats), *Urocystis cepulae* (onion smut). *Ustilago maydis* (corn

smut) is sold as a gourmet food called "corn mushroom." Economically, smuts cause extensive damage to crops and consequent reductions in yields.

Urocystis cepulae Onion Smut

Black teleutospores (f) form an infestation on bulbs of onions (g). This is commonly seen on commercially sold onions.

Jelly Fungi (Auriculariales). Fruiting bodies of gelatinous material are produced. When wet, basidia are formed. Most genera are saprobic, living on dead organic matter. A few genera are parasitic on mosses and flowering plants. Of interest... *Herpobasidium deformans* (blight of honeysuckle).

Auricularia auricula Ear Fungus

The gelatinous fruiting body (h) resembles a human ear.

Jelly Fungi (Tremellales). Fruiting bodies are gelatinous with leaf-like folds that vary in color with species from white, pink, yellow, and orange to red.

Tremella mesenterica

This jelly fungus (i) is found on hardwood tree bark (j). Some species are edible.

Jelly Fungi (Dacrymycetales). Waxy, bright-colored gelatinous fruiting bodies are produced. The yellow coloring is due to β -carotene pigment. They grow on living or dead trees.

Dacryopinax spathularia

This jelly fungus (k) is found on rotting wood (l).

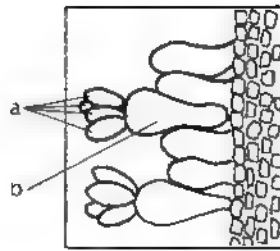
COLOR CODE

yellow:	basidiospore (a), onion (g)
tan:	basidium (b), fruiting body (h)
orange:	telium (e), fruiting body (k)
brown:	gall (c), wood (l)
green:	cedar (d)
pale yellow:	fruiting body (i)
gray:	bark (j)

Club Fungi

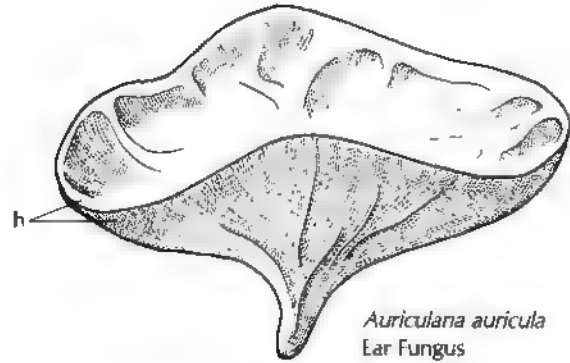
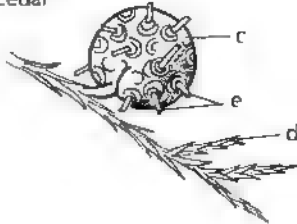


Basidiocarp
gill section

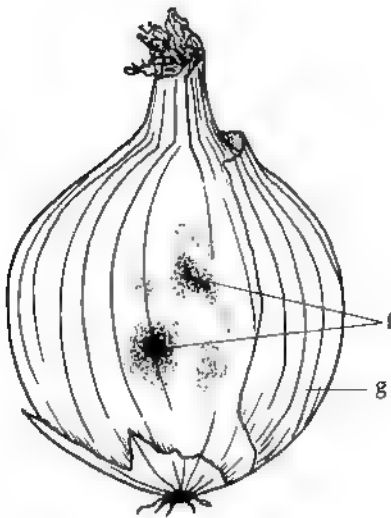


Basidia
with basidiospores
× 450

Gymnosporangium
gall on cedar
× 1

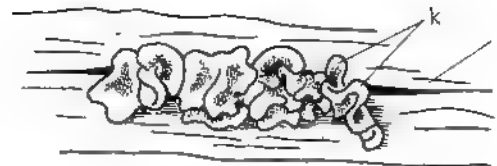
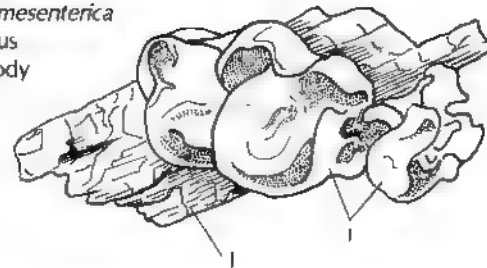


Auricularia auricula
Ear Fungus
fruiting body
× 1½



Urocystis cepulae
Onion Smut
on onion
× 1

Tremella mesenterica
Jelly Fungus
fruiting body
× 1



Dacryopinax spathulana
Jelly Fungus
fruiting body
× 1

Gill Fungi

Gill, Pore, Coral, and Toothed Fungi (Agaricales).

In this order, a basidium usually produces 4 basidiospores, which are forcibly discharged from the fruiting body. Fruiting bodies may occur in forms commonly known as mushrooms, toadstools, shelves, corals, and toothed fungi.

A "spore print" (basidiospore collection) can be made by placing a fruiting body cap with gills or pores half on white paper, half on black paper. If dark spores are discovered, use an entire cap on white paper and if light spores use black paper. Spore color is useful for identification. It can be white, pink, yellow, brown, purple, or black.

Of interest...**food:** *Agaricus campestris* (commercial mushroom), *Calvatia gigantea* (giant puffball), *Cantharellus cibarius* (chanterelle), *Lentinus edodes* (shiitake, high in vitamin B₁₂, cobalamin; grown commercially on white oak logs to produce fruiting bodies for up to 10 years after inoculating the mycelium in holes drilled in the logs. Logs are stacked criss-crossed like Lincoln logs in the shade of deciduous forests and watered frequently with sprinklers. This technique is widely used in Korea and now in the U.S. by Korean entrepreneurs.), *Pleurotus ostreatus* (oyster mushroom, this mushroom is grown commercially on vertically stacked sections of American elm, *Ulmus americana*, trunks covered with black plastic film.);

wild: *Amanita verna* (destroying angel, contains a deadly poison that destroys liver and kidney cells), *Armillaria mellea* (honey mushroom, causes root rot of trees, exhibits bioluminescence or "fox-fire" in mycelia-penetrated organic matter), *Boletus edulis* (porous mushroom), *Ganoderma applanatum* (shelf or bracket fungus, a type of artist's fungus, so called because marks made on the smooth white underside will remain when the mushroom dries), *Marasmius oreades*

(fairy ring mushroom), *Polyporus sulphureus* (sulfur mushroom, causes wood rot of trees), *P. squamosus* (heart rot of trees), *Psilocybe* spp. (hallucinogenic mushrooms). *Psilocybe* mushrooms in Mexico are collected, dried, and served in pairs by women in all-night religious ceremonies of Amerinds, as documented by the famous Harvard University botanist, Charles Evans Schultes.

Amanita muscaria Fly Amanita, Fly Agaric

The fruiting body of a gill mushroom begins as a mass of hyphal cells and enlarges into a "button." At this stage, the fruiting body is surrounded by a **universal veil** (d). As expansion of the gills (**lamellae**) takes place, the veil is broken. The veil may remain as patches or scales (b) on the cap (**pileus**) and as veil remnants (c) or as a cup (**volva**) at the base of the stalk (**stipe**).

Some species of agarics also have an inner or **partial veil** (d) between the developing stalk (e) and gills (f). When the partial veil is broken upon expansion of the gills, it may remain attached to the stalk as a ring (**annulus**, g) or remain attached to the margin of the cap, hanging down as a curtain, as in *Cortinarius*.

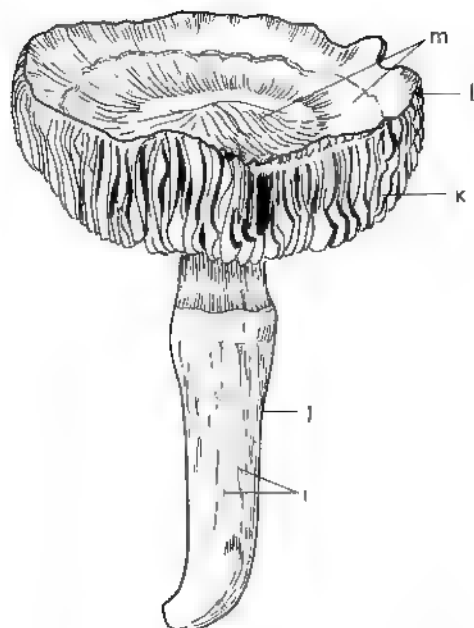
The microscopic basidia are borne on the inner surface of the gill. Individual cap (h) color in this species varies from white, yellow, and orange to red. This is a poisonous mushroom, found mostly in mycorrhizal association (see 12) with roots of aspen and conifer trees.

Cortinarius

Remains of the partial veil, which hangs down from the cap as a curtain (cortina), form web-like lines (i) on the stalk (j). As the cap expands, gills (k) are exposed. This fruiting body was found in a beech-maple forest.

COLOR CODE

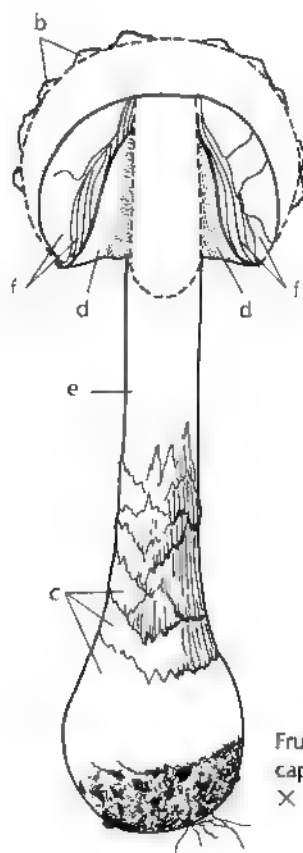
white:	scales (b), veil remnants (c), partial veil (d), stalk (e), gills (f), annulus (g)
orange-red:	cap (h)
light tan:	stalk (j), gills (k)
yellow:	cap margin (l)
yellow-brown:	cap center (m)



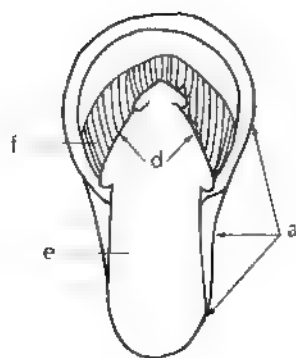
Cortinarius
fruiting body
× 1



Fruiting Body
× 1



Fruiting Body
cap, vertical section
× 1



Fruiting Body
button stage
vertical section
× 1

Amanita muscaria
Fly Amanita

Gill and Pore Fungi

Agaricales (continued)

Coprinus comatus Shaggy Mane

As the white fruiting body matures, the gills undergo self-digestion with black basidiospores released in an inky black fluid. This mushroom is found in lawns, golf courses and fields and is edible and preferred in the button stage before dripping black fluid. Remnant of a veil (a) remains on top. Caution: when eating this mushroom, alcoholic drinks should not be taken; otherwise, you can become quite ill!

Chantharellus cinnabarinus Cinnabar Chanterelle

Basidiospores are produced on blunt gills (b). With age, the cap (c) becomes funnel-shaped on the fruiting body stalk (d). This mushroom is edible and found in forests throughout the United States and Canada. It is considered a gourmet treat, sold in grocery markets and used in restaurant offerings.

Russula emetica Emetic Russula

The fruiting body has a stout stalk (e) supporting a bright red cap (f) with white, brittle gills (g). This fragile fruiting body is probably poisonous.

Suillus americanus

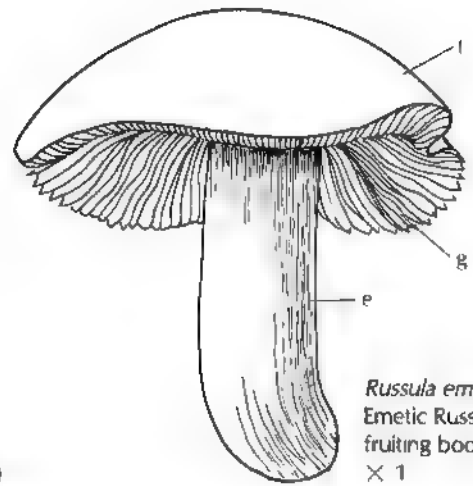
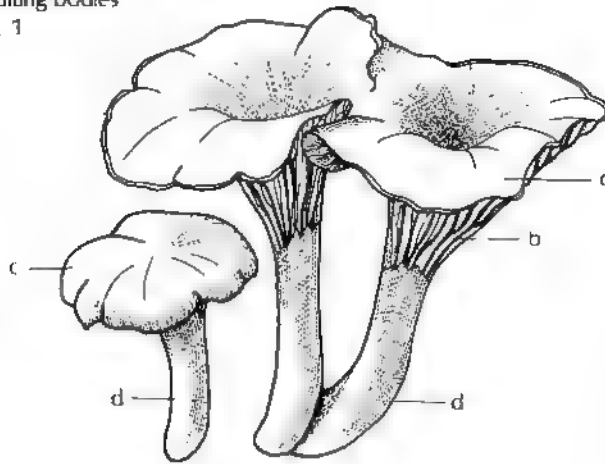
Instead of gills, this mushroom has fleshy pores (h) and is therefore designated as a **bolete**. Basidia line the inner surfaces of layers of tubes with pore openings. The fruiting body is fleshy and decays quickly. Brown scales (i) dot the yellow cap (j). It is edible, but little flesh remains after the tubes have been removed.

COLOR CODE

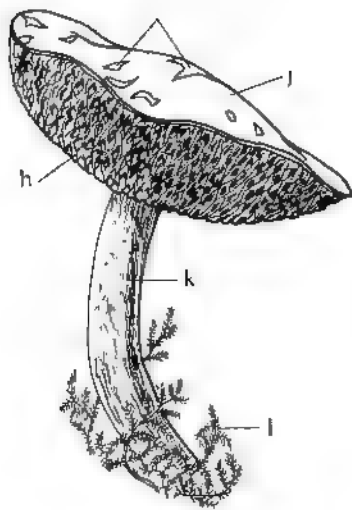
light tan:	veil remnant (a)
dark orange:	gills (b), cap (c), stalk (d)
pale pink:	stalk (e)
red:	cap (f)
white:	gills (g)
yellow:	pores (h), cap (j), stalk (k)
brown:	scales (i)
green:	moss (l)

Club Fungi

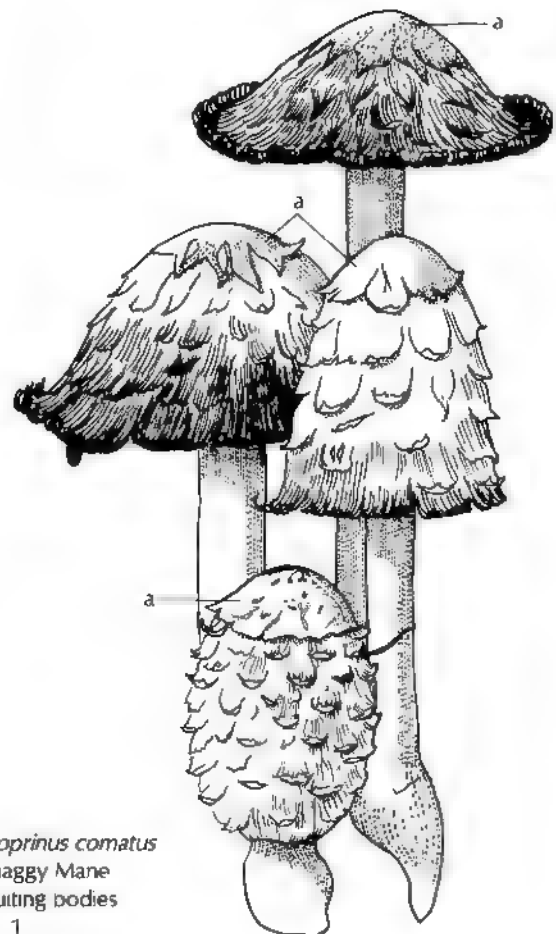
Cantharellus cinnabarrus
Cinnabar Chanterelle
fruiting bodies
× 1



Russula emetica
Emetic Russula
fruiting body
× 1



Suillus americanus
Bolete Fungus
fruiting body
× 1



Coprinus comatus
Shaggy Mane
fruiting bodies
× 1

Pore, Coral, and Toothed Fungi

Agaricales (continued)

Coriolus (Polyporus, Trametes) versicolor **Turkey-tail Fungus**

In polypore (= many pores) fungi, basidia are formed on the inner surface of leathery pores (a) on the lower portion of the fruiting body (b). This fan-shaped bracket fungus is found on rotting wood. The bands of tan, brown, white are like the colors of a turkey's tail feathers, and thus account for the common name.

Fomes formentarius **Rusty-hoof Fungus**

This perennial polypore adds new growth (c) yearly to the woody bracket-type fruiting body (d). It is parasitic on birch (*Betula*) and beech (*Fagus*, e) and some other hardwood deciduous trees. It is shaped like a horse's hoof and is common in northern temperate zones.

Irpex lacteus **Crust Polypore**

A crust-like fruiting body (f) of this polypore grows on the lower surface of dead tree limbs (g).

Clavulinopsis fusiformis **Coral Fungus**

The fruiting body (h) in this coral fungus is simple and unbranched.

Ramaria stricta **Straight Coral Fungus**

This coral fungus has a more complexly branched fruiting body (i). It is usually found on rotting beech (*Fagus*) wood.

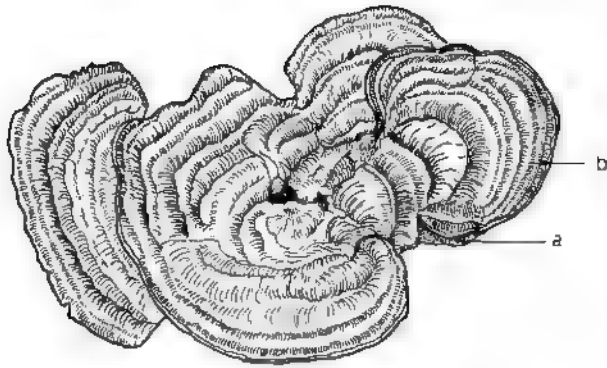
Hericium **Toothed Fungus**

Basidia are produced on downward-pointed, tooth-like projections on the fruiting body (j). It is found on dead deciduous hardwood trees.

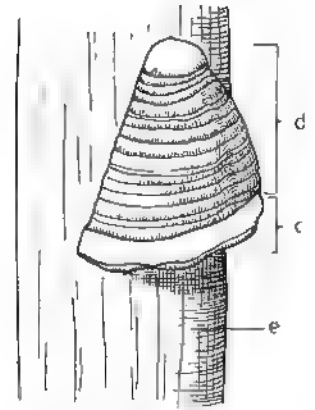
COLOR CODE

tan-brown-white bands:	fruiting body (a, b)
rust (yellow-brown-red):	new growth (c)
dark and light gray bands:	fruiting body (d)
brown:	bark (e)
yellow-tan:	fruiting body (f, i)
gray:	bark (g)
orange:	fruiting body (h)
white:	fruiting body (j)

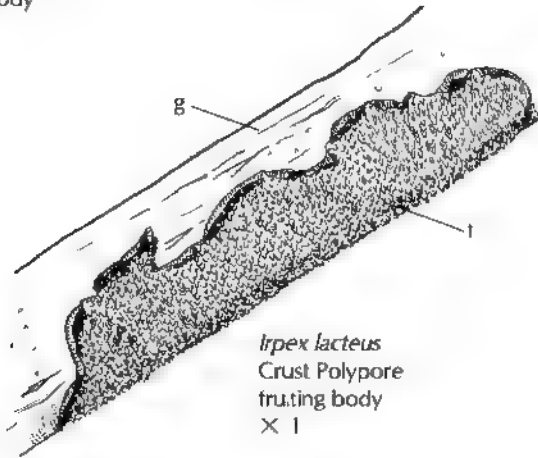
Club Fungi



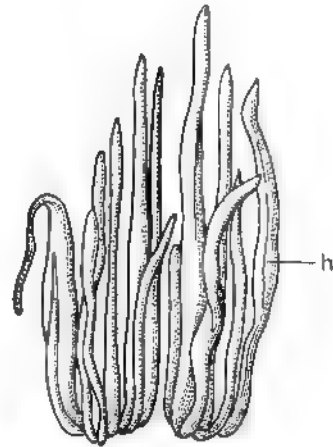
Coriolus versicolor
Turkey-tail Fungus
fruiting body
× 1



Fomes fomentarius
Rusty-hoof Fungus
fruiting body
× ½

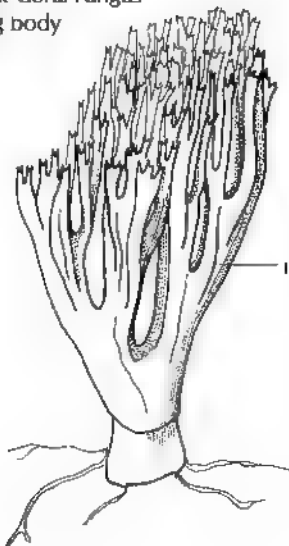


Irpex lacteus
Crust Polypore
fruiting body
× 1



Clavulinopsis fusiformis
Coral Fungus
fruiting body
× 1

Ramaria stricta
Straight Coral Fungus
fruiting body
× 1



Hericiium
Toothed Fungus
fruiting body
× 1



Puffballs, Stinkhorns, Bird's-nest Fungi

Puffball Fungi (Lycoperdales). Spores are dispersed by wind from puffball fruiting bodies. An inner fertile portion, called the **gleba**, is composed of basidiospores and sterile thread-like structures (**capillitia**). Powdery masses of spores are exposed when the puffball wall (**peridium**) disintegrates, or emerge in a cloud from an opening (**ostiole**) when the flexible peridium is disturbed.

Of interest . . . *Calvatia gigantea* (giant puffball) found in mostly open or sometimes wooded areas and after rains in late summer or early autumn and is edible when pure white inside, *Geastrum* and *Astraeus* (earthstars), *Lycoperdon* (stalked puffball).

Geastrum Earthstar

This type of puffball has a star shape when the rigid outer wall or peridium (a) becomes wet and splits open. An inner flexible peridium (b) is exposed. A single pore (ostiole, c) for spore dispersal occurs at the center.

Lycoperdon Stalked Puffball

At maturity, a powdery gleba of spores (d) puffs out of an ostiole (e) in the peridium (f) due to rain drops or other physical disturbances.

Stinkhorn Fungi (Phallales). Basidiospores are formed within a gleba. A receptacle, bearing the gleba, emerges from a protective enclosure, the peridium. As the gleba breaks down, the basidiospores are exposed in a gelatinous mass at the top of the stinkhorn. The foul smell of the mass attracts flies, which disperse the spores.

Of interest . . . *Dictyophora* (collared stinkhorn), *Clathrus* (net stinkhorn), *Mutinus* (dog stinkhorn), *Phallus* (common stinkhorn)

Dictyophora duplicata Collared Stinkhorn

At the egg stage, the peridium (g) encloses the gleba (h) where basidia and basiospores are formed. The receptacle (i) and stalk (k) will enlarge and emerge from the peridium, which remains at the base.

Mutinus caninus Dog Stinkhorn

From the broken peridium (k), a pink stalk (l) emerges. The dark pink receptacle (m) at the top of the fruiting body is covered by a green, slimy mass (gleba, n) of spores.

Bird's-nest Fungi (Nidulariales). The fruiting body appears as a hollow nest filled with egg-like peridioles, which contain basidiospores. The nest acts as a splashcup. Raindrops cause the peridioles to bounce out of the fruiting body. The peridiole's sticky covering adheres to nearby surfaces where the spores are then released. This type of fungus is often found on rotting bark mulch used in gardening and on deciduous forest duff litter.

Of interest . . . *Nidularia* (white bird's-nest fungus), *Crucibulum* (common bird's nest fungus), *Cyathus* (striate bird's-nest fungus).

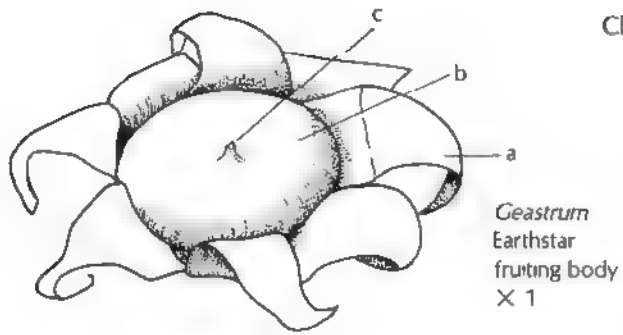
Crucibulum vulgare Common Bird's-nest Fungus

This genus is often found on wood chip (o) paths and on the forest "floor." Small peridioles (p) are formed in the nest-like fruiting body (q).

Of interest . . . many of these fungi are important in forest tree communities in causing the breakdown of leaf/twig litter and dead tree branches to form organic humus (like compost) over the forest floor. This forms a great substratum for forest tree seed germination and subsequent development of seedlings.

COLOR CODE

tan:	peridium (a, b, f, g, q)
green-brown:	gleba (h, n)
white:	receptacle (i), stalk (j), peridium (k), peridiole (p)
light pink:	stalk (l)
dark pink:	receptacle (m)
brown:	wood chips (o)

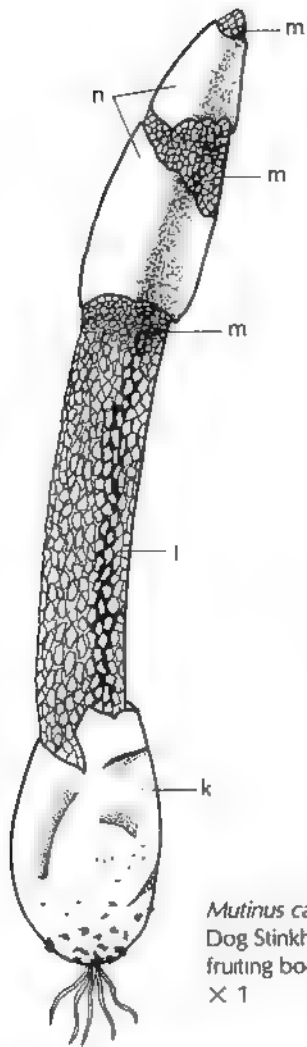


Geastrum
Earthstar
fruiting body
× 1

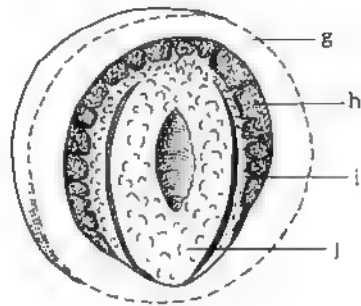
Club Fungi



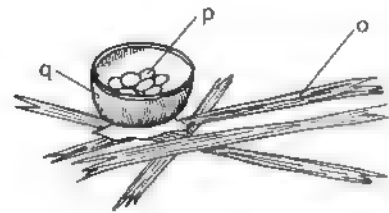
Lycoperdon
Stalked Puffball
fruiting body
× 1



Mutinus caninus
Dog Stinkhorn
fruiting body
× 1



Dictyophora duplicata
Collared Stinkhorn
fruiting body, egg stage
vertical section
× 1



Crucibulum vulgare
Common Bird's-nest fungus
fruiting body
× 1

Lichens

A **lichen** is an association of a fungus (mycobiont, mykes = fungus + bios = life) and an alga (phycobiont, phykos = alga + bios = life). The fungus is an ascomycete or a basidiomycete. The algal partner is either a blue-green or a green alga. The association can be **parasitic**, in which the fungus eventually kills the algal cells; or it can be **mutualistic**, in which both fungus and algal cells benefit. Mutual benefits include algal nutrition that benefits the fungus because of the presence of chlorophyll for photosynthesis in the alga. And protection for the smaller alga is provided by the fungus. Lichens can tolerate harsh conditions such as dryness, arctic cold, and bare rock habitats. They possibly live for thousands of years.

Characteristics. The upper cortex (a) is the outer protective layer with fungal hyphae gelatinized and cemented together. Next is the algal layer (b). Most lichens are associated with the unicellular green alga, *Trebouxia*. So far, over 30 genera of algae have been found associated with lichens. Most of the lichen body (thallus) is made up of medulla (c) with hyphae loosely interwoven. The medulla retains moisture and stores food.

The thallus may take different forms. **Crustose lichens** are extremely flat and only ascocarps (fruiting bodies of the fungus, see 48) may be visible. (See drawing opposite of *Graphis scripta*.) They are found on rocks and trees. The medulla may be embedded in rock surfaces. **Foliose lichens** have a leafy thallus and may have a compacted lower cortex (d) and root-like anchoring devices called **rhizines** (e). (See drawings opposite of *Xanthoria* and *Physcia aipolia*.) **Fruticose lichens** with three-dimensional projections, called podetia, arise from a scale-like, loosely-attached (squamulose) base. (See drawings opposite of *Cladonia cristatella* and *Cladonia pyxidata*.)

Reproduction. Various vegetative structures may be found on lichens, such as soredia and isidia. **Soredia** originate in the algal layer as masses of algae cells with a few gelatinized hyphae erupting through cracks in the surface cortex. By a process of breaking off, new lichen thalli are formed. An **isidium** is a projection on a foliose or fruticose lichen that serves as a vegetative propagule when broken off. Depending on the type of fungus, fruiting bodies with ascospores or basidiospores are produced.

Lichens also have asexual structures called pycnidia, flask-shaped structures that produce microconidia. The

fungal spore or microconidium must form an association with an appropriate alga in order to live.

Of interest . . . **arctic animal food:** *Cetrarias*, *Cladonia* spp. (reindeer mosses), *Usneas*; **human skin rash:** *Evernias*, *Usneas*; **dye:** *Letharia*, *Ochrolechia*, *Parmelia*, *Roccella*; **ecosystem succession role:** lichens are often the first colonizers of bare substrate, breaking up rocks, due to their secretions of lichen acids; thalli form an anchor base for later colonizing plants.

Sac Fungi: Euascomycetidae (Lecanorales)

Graphis scripta Script Lichen

Found on hardwood trees, this crustose lichen thallus (f) has dark eruptions of apothecia (g).

Xanthoria

Found on rotten wood, the thallus (h) of this foliose lichen has apothecia composed of gray-green receptacles (i) with brightly colored ascospore layers (hymenia, j).

Physcia aipolia Blister Lichen

This foliose lichen has a white-spotted thallus (k) with apothecia emerging from the surface cortex. The fertile layer of asci (hymenium, l) is gray with a gray-green receptacle (m).

Cladonia cristatella British Soldiers

The fruticose podetium (n) arises from a squamulose thallus (o). Red apothecia (p) dot the top of the podetia.

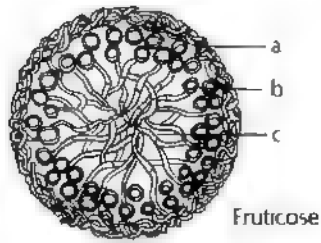
Cladonia pyxidata Pyxie Cup

The fruticose podetia (q) resemble pyxie cups arising from a squamulose thallus (r). Brown apothecia (s) dot the cup rims.

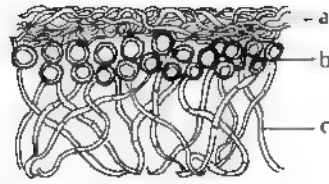
COLOR CODE

gray:	cortex (a, d), thallus (f), hymenium (l)
green:	algae (b)
white:	medulla (c)
black:	rhizines (e), apothecia (g)
gray-green:	thallus (h, k, o, r), receptacle (i, m), podetium (n, q)
yellow-orange:	hymenium (j)
red:	apothecium (p)
brown:	apothecium (s)

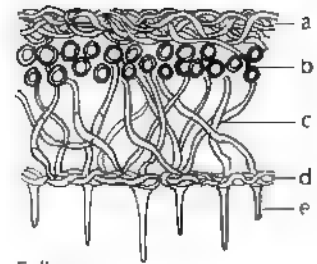
Lichens



Fruticose

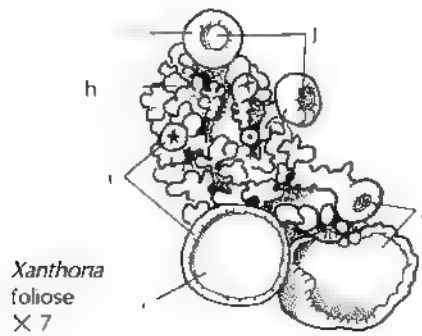


Crustose, Squamulose

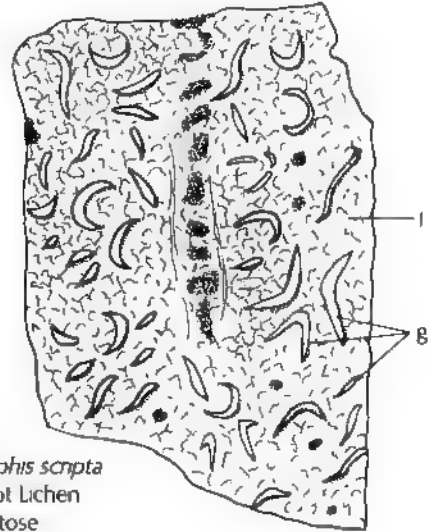


Foliose

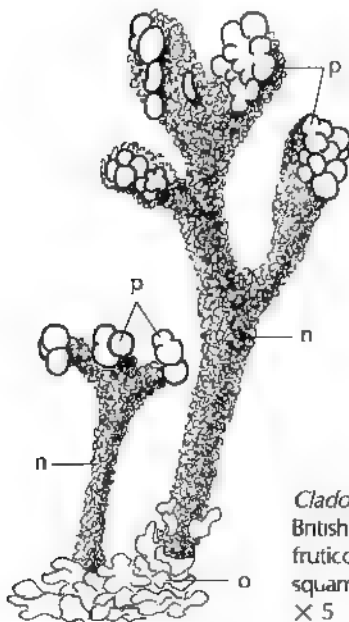
Lichen Structure diagrams



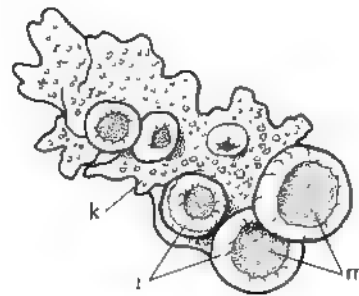
Xanthoria
foliose
× 7



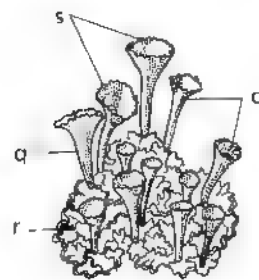
Graphis scripta
Script Lichen
crustose
× 5



Cladonia cristatella
British Soldiers
fruticose "soldiers"
squamulose base
× 5



Physcia alpicola
Blister Lichen
foliose
× 7



Cladonia pyxidata
Pyxie Cup Lichen
fruticose "cups"
squamulose base
× 1

Dinoflagellates

Fossils of dinoflagellates extend back to the Ordovician time of the Paleozoic. Most are marine.

Characteristics. These microscopic organisms are unicellular and are usually motile due to the presence of a pair of unequal flagella. There are diverse forms. Nutrition varies from self-feeding (**autotrophic**) to mutually beneficial (**mutualistic**) to dependency upon a host (**parasitic**). Pigments are chlorophylls a and c, carotene, and the xanthophyll, peridinin, which gives a gold-brown color to the organisms. Starch is the primary stored food.

The nucleus is large and the chromosomes remain visible at all stages (see 6), while the nuclear membrane remains intact. Some dinoflagellates have light-sensitive eyespots. Other marine species are bioluminescent: when cells are vigorously agitated, they give off flashes of light.

Reproduction. Asexual reproduction occurs by cell division and cyst formation. Sexual reproduction is by sex cells (gametes) that look alike (**isogamy**) or unlike (**anisogamy**).

Of interest . . . “**blooms**” or “**red tides**,” under optimal conditions rapid reproduction produces heavy concentrations of dinoflagellates that color the ocean red, red-brown, or yellow; **toxins**: these “blooms” can be toxic

to other organisms in different ways: killing only fish, killing mainly invertebrates, or not killing but concentrating their toxins in bivalve mollusks. The toxins produced by species of *Gonyaulax* are thousands of times more potent than cocaine, and may cause human death within 12 hours after consumption of affected bivalves, but in low concentrations, their toxin usually produce severe digestive upsets.

Dinophyceae. This class of dinoflagellates is made up of biflagellated motile cells. One flagellum is coiled around the transverse girdle groove (cingulum), providing a rotating movement. The other flagellum is located in a longitudinal groove (sulcus); it functions as a propellant from the posterior end.

Gymnodinium

The name means “naked whorl,” as it is without armored plates. Structures shown are the girdle groove (a) with flagellum (b) and the sulcus groove (c) with flagellum (d). Many chloroplasts (e) are visible.

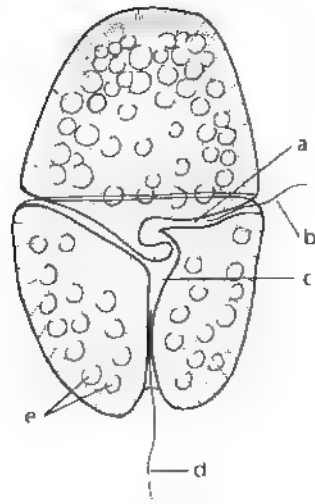
Ceratium

The name means “horned.” Armored plates (f) ornamented with pits cover the organism. Structures shown are the girdle groove (g) with flagellum (h) and the sulcus groove (i) with flagellum (j).

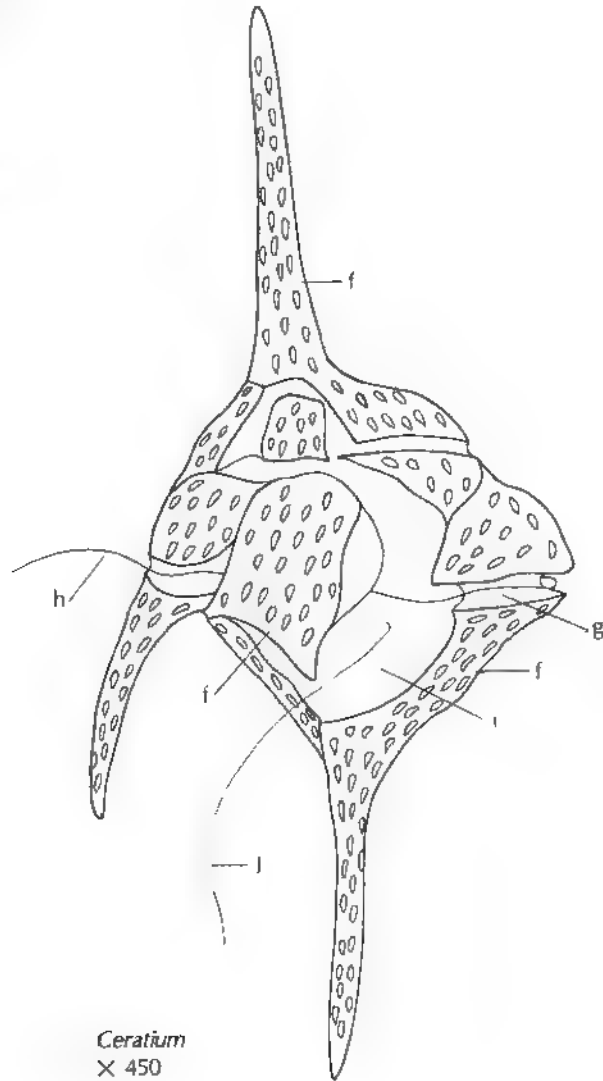
COLOR CODE

gold-brown: chloroplasts (e), plates (f)

Dinoflagellates



Gymnodinium
× 450



Ceratium
× 450

Golden Algae, Yellow-green Algae, Diatoms

This diverse group of algae has several common features: a complex carbohydrate food reserve called chrysolaminaran (leucosin); more carotene pigments than chlorophylls, thus the gold and yellow-green colors; and chlorophylls a and c. The pigment, fucoxanthin, occurs in some of the divisions. Forms range from amoeboid cells, flagellated cells, filaments, to parenchymatous thalloid types.

Golden Algae (Chrysophyceae). Members in this group live mainly in fresh water. There are a few marine forms. Some have cell coverings that may contain silica. Two-part resting spores (statocysts) are formed when unfavorable conditions occur. Asexual reproduction is by fragmentation and production of an asexual reproductive cell (zoospore). Sexual reproduction is not well-known.

Dinobryon

This fresh water alga forms free-swimming colonies of biflagellated cells. The protoplast (a) is connected by a thin strand to its protective covering: a transparent, open-ended, vase-shaped lorica (b). The protoplast has 2 flagella (c) of unequal length, an eyespot (d) and a chloroplast (e).

Yellow-green Algae (Xanthophyceae). Fresh water habitats are typical for this group. They form a scum in standing water, and some occur on the surface of moist mud and on tree trunks. There are less than 100 known species.

Vaucheria

This alga is a branching filament (f) containing many chloroplasts (g). It may form mats under moist, greenhouse clay pots. The filament has no cross-walls except where reproductive chambers are formed. Reproduction is by asexual zoospores and by the sexual union of a small motile sperm with a large non-motile egg (**oogamy**). An antheridial branch (h) containing sperm cells (i) forms laterally on a filament. A biflagellated sperm cell swims to a pore (j) in the oogonium (k) to fertilize the egg (l). The fertilized egg develops into an oospore (m), which remains in the oogonium as a resting spore until germination occurs.

Diatoms (Bacillariophyceae). Two hundred surviving genera of unicellular diatoms are known, with as many as 100,000 species. Diatom walls (**frustules**) have the structure of a narrow box with a lid. The lid, called the epivalve, fits over the box or hypovalve. The overlapping area is the girdle region. Reproduction is by cell division. It involves separation of the epivalve and hypovalve, with new, smaller container walls being formed. When an ultimate, minimum size reduction is reached, new cells are formed by the fusion of the protoplasm of two cells. Diatoms also have sexual reproduction.

Of interest . . . **ecosystem:** diatoms, the major component of plankton—which form the base of aquatic food chains, are the single most important group of algae. In relation to other families, diatoms also supply the major percentage of the world's oxygen supply. They are affected by temperature, pollution, and light. Some characteristic species of diatoms and other algae are indicators of polluted water, while other species are indicative of clean, non-polluted water; **fossils: diatomaceous earth** is represented by the silica remains of diatoms; it is used for filters, abrasives, insulation, in pavement paints, and as an indicator of oil- and gas-bearing formations.

Pinnularia

The epivalve (n) portion fits over the hypovalve (o) as shown in this diatom diagram.

Asterionella

This diatom forms a star-shaped colony of cells (p).

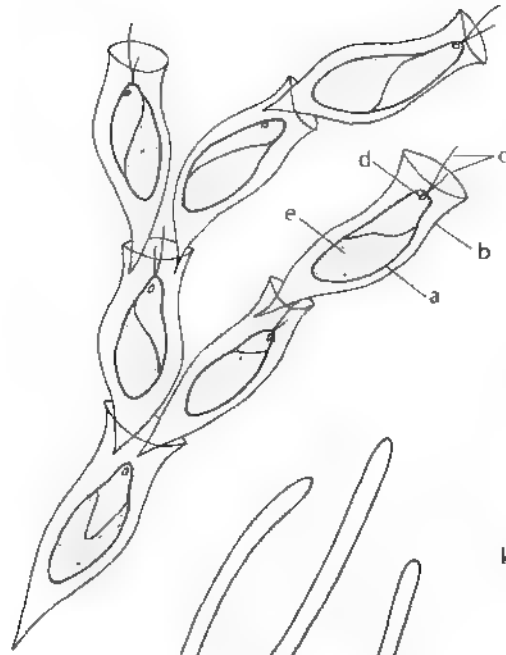
Coscinodiscus

Surface striations (q) of puncture holes mark the wall (r).

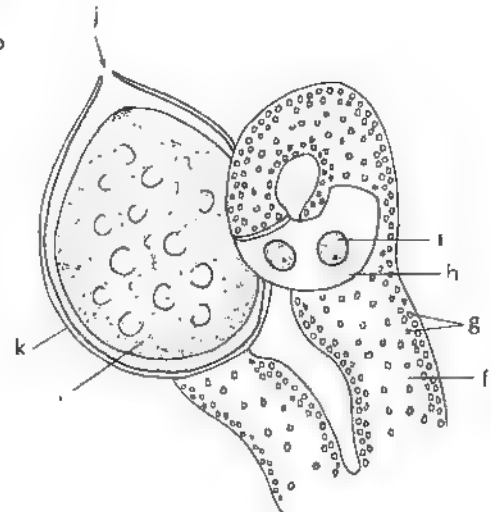
COLOR CODE

red:	eyespot (d)
yellow:	protoplast (a), diatoms (n, o, p, q, r)
yellow-brown:	chloroplast (e)
yellow-green:	filament (f), oospore (m)
tan:	sperm cells (i), egg (l)

Golden Algae

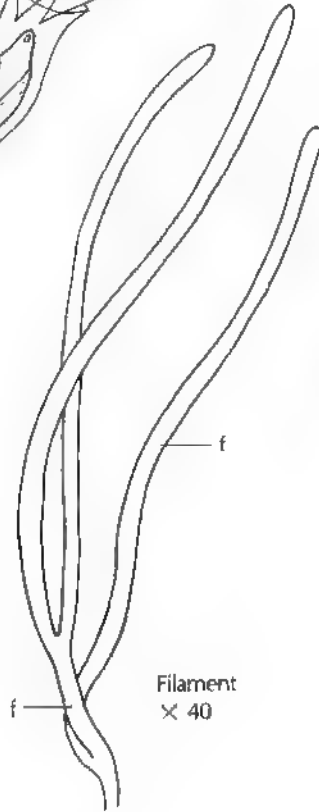


Dinobryon
colony of cells
× 450



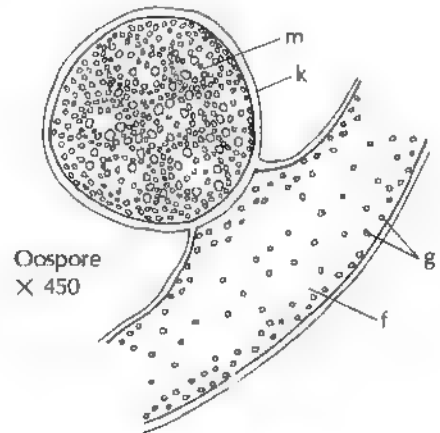
Sexual Structures
× 450

Yellow-green Algae



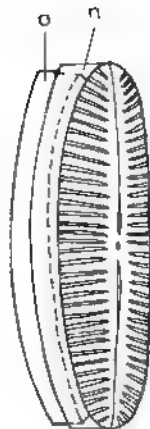
Filament
× 40

Vaucheria

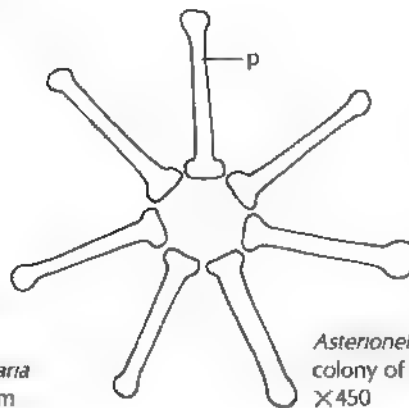


Oospore
× 450

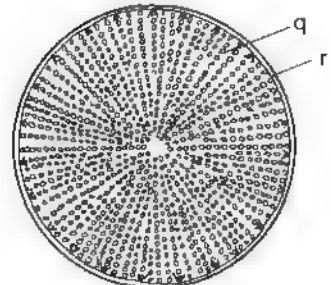
Diatoms



Pinnularia
diagram



Asterionella
colony of cells
× 450



Coscinodiscus
× 150

Red Algae

The red algae, with about 400 genera, are mostly marine with only a few known freshwater genera. Most are found in tropical areas where they occur at great depths or along intertidal regions.

Characteristics. Their color varies greatly depending on the amount of pigments and can range from shades of green, red-brown, bright red, blue, and purple-blue to black. Usually, the green pigments, chlorophylls a and d, are masked by the phycobilin pigment (red phycoerythrin and blue phycocyanin). Other pigments include carotenes and xanthophylls (see 4).

Red algae are relatively simple vegetative organisms but have complex reproductive systems. The primary food reserve is floridean starch (a polysaccharide = carbohydrate made up of many glucose units). There are a few microscopic unicellular forms, but most have branched filaments or flat leaf-like forms.

Reproduction. Asexual reproduction occurs by fragmentation and production of vegetative spores. Red algae are divided into two subclasses. In the more primitive Bangiophycidae, sexual reproduction is mostly absent. In the more advanced Florideophycidae, sexual reproduction is oogamous: non-flagellated male gametes (**spermatia**) are carried by water to a stationary female gamete-bearing structure called the **carpogonium**.

Of interest ... **colloids:** *Chondrus crispus* (**carageenan**, used as a stabilizing agent in milk products, jellied foods, cosmetics, insect sprays, and water-based paints), *Gloiopeltis* (**funori**, used as a water-soluble sizing in water-based paints and as a flexible starch in laundering); **agar:** *Gelidium* (agar, used as a culture medium in microbiology, as non-irritant bulk in human intestinal disorders, and to make pill capsules); **coral**

reefs: *Corallinna*, *Lithothamnium*, and *Galaxaura* accumulate calcium carbonate, which contributes to reef-building; **ecosystem:** red algae provide food for marine animals; **human food:** *Chondrus crispus* (Irish moss), *Porphyra* (nori), *Palmaria* (dulse).

Porphyra Nori

This genus, in the subclass Bangiophycidae, has a leafy thallus (a) with rhizoidal cells at the base for attachment to rocks.

Polysiphonia

Placed in the subclass Florideophycidae, this genus has a filamentous thallus (b) constructed of many (poly) tubes (siphons, c); hence its name. Male gametophyte individuals produce special branchlets called **trichoblasts** (d), that bear spermatia (e). Female gametophyte individuals produce urn-shaped structures called **cystocarps** (f), which contain egg cases (**carpogonia**). After fertilization and maturation, carpospores (g) are released. Carpospores develop into a tetrasporophyte generation, producing tetraspores that germinate into male or female gametophytes (gamete-bearing). Both the tetrasporophyte and the gametophyte generations have the same external filamentous appearance.

Of interest ... to preserve filamentous marine plant specimens, place the plant in a large shallow pan of water and allow it to float naturally. Then slide art paper, bond paper, or, ideally, rag paper under the specimen. Slowly lift the paper with the plant on top and drain excess water off one end. Blot the bottom of the paper on newsprint, then place plant-on-paper in a single folded sheet of newspaper. Stack with blotters and newspaper and press with weights or place in a plant press until dry.

COLOR CODE

red-purple: thallus (a)
red: thallus (b), tubes (c), trichoblast (d, e),
cystocarp (f), carpospores (g)

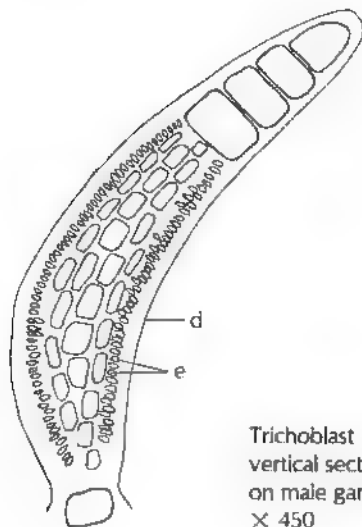
Red Algae



Porphyra
habit
× ½

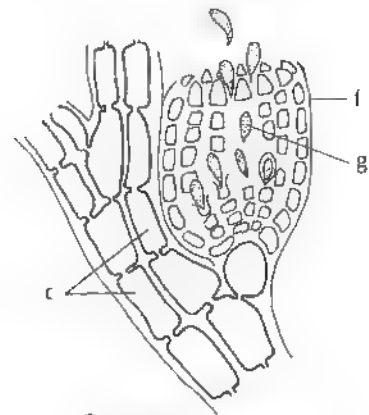


Habit
× 1



Trichoblast
vertical section
on male gametophyte
× 450

Polysiphonia



Cystocarp
on female gametophyte
× 200

Green Algae

Green algae constitute a very ancient group of plants with fossils occurring back to early periods of the Paleozoic era. They are mainly freshwater plants, but also occur in saltwater, in soil, on tree bark, and on snow.

Characteristics. Green algae forms are unicellular, colonial, filamentous, membranous (resembling leaves), and tubular. The cells have many of the organelles found in cells of higher plants, including a rigid cell wall; a nucleus with one or more nucleoli; a large vacuole; well-organized chloroplasts; pigments of chlorophylls a and b, carotenes, and xanthophylls; self-feeding nutrition (autotrophic); and pyrenoids associated with starch formation. Motile forms usually have two whiplash flagella of equal length. There are many varying types of asexual and sexual reproduction.

Of interest . . . **phylogeny:** green algae are considered to be on the direct evolutionary line to higher vascular plants; **ecosystem:** they contribute to the freshwater plankton of the food chain.

Note: Of the 450 genera, the few illustrated here are microscopic, with the exception of *Acetabularia*, which is macroscopic

Chlamydomonas

This unicellular alga is motile by means of two flagella (a). The cup-shape chloroplast (b), that contains a red eyespot (c) and a pyrenoid (d), surrounds the nucleus (e).

Eudorina

Sixteen cells make up this **coenobium** (a colony of a fixed number of cells). A gelatinous sheath (f)

surrounds the flagellated (g) cells. The chloroplast (h) contains an eyespot (i).

Cladophora

This alga has branched filaments whose cells contain numerous pyrenoids (j) in reticulate chloroplasts (k).

Acetabularia

This marine alga, known as "mermaid's wineglass," is one immense cell with a giant nucleus (l) in the basal rhizoid (m). The nucleus migrates to the cap (n) where reproductive cysts are formed.

Scenedesmus

This is a coenobium composed of four cells that are joined laterally. The laminate chloroplast (o) contains a pyrenoid (p). There is one nucleus (q) per cell.

Micrasterias

The cell wall, enclosed by a gelatinous sheath (r), is divided into two halves. Each half of this unicellular alga has a chloroplast (s) with pyrenoids (t). The nucleus is located at the contraction (isthmus, u) between the cell halves. For asexual propagation, the nucleus divides in half, the cell splits into two halves and separates. Then each half grows a new partner to form a cell as illustrated. This plant occurs in freshwater ponds and lakes.

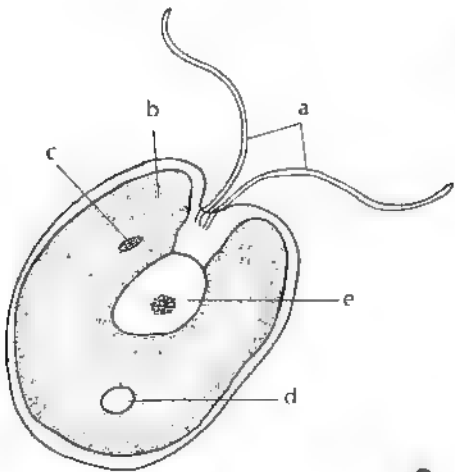
Spirogyra

Spirogyra is an unbranched filamentous freshwater alga. One cell in a filament is shown. It has two spiral chloroplasts (v) with numerous pyrenoids (w). The nucleus (x) is suspended in the center by threads of cytoplasm.

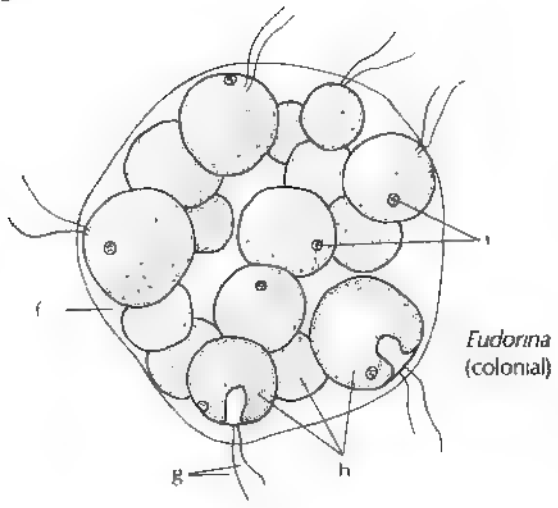
COLOR CODE

colorless: flagellum (a, g), sheath (f, r), rhizoid (m)
white: pyrenoid (d, j, p, t, w)
gray: nucleus (e, l, q, u, x)
red: eyespot (c, e, i)
green: chloroplast (b, h, k, o, s, v), cap (n)

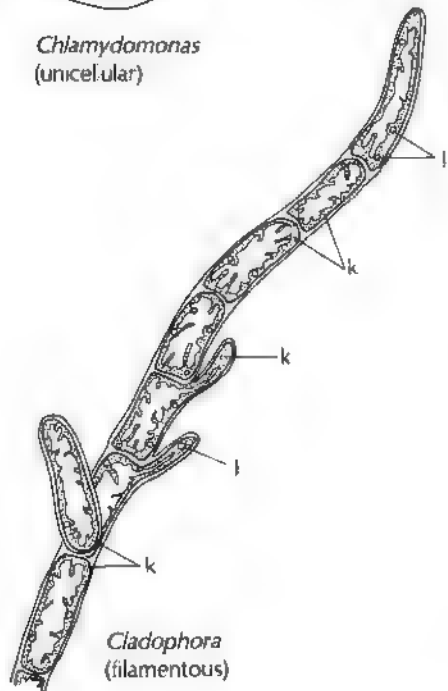
Green Algae



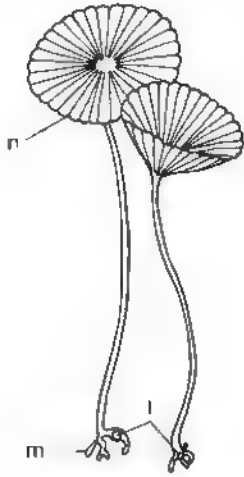
Chlamydomonas
(unicellular)



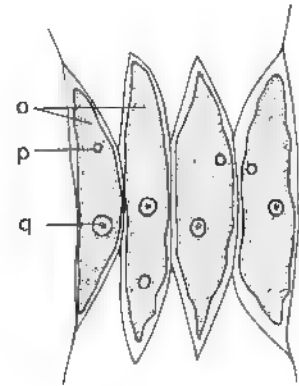
Eudorina
(colonial)



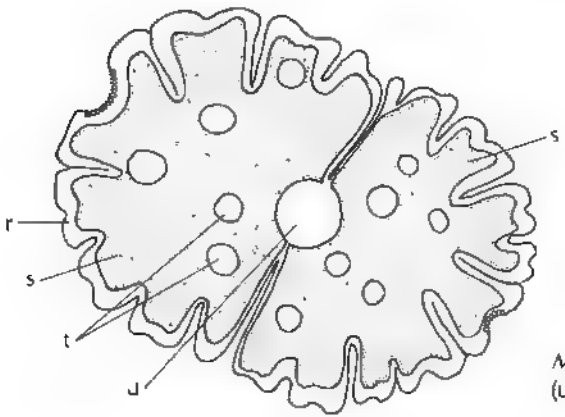
Cladophora
(filamentous)



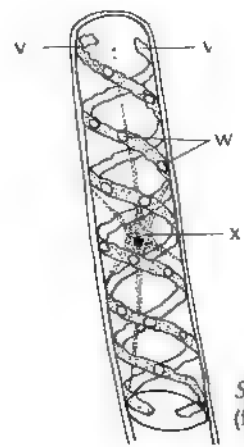
Acetabularia
(unicellular)
X 1½



Scenedesmus
(colonial)



Micrasterias
(unicellular)



Spirogyra
(filamentous)

Brown Algae

The algae in this division are mainly marine. They live along cooler coastal, intertidal areas, forming large beds of brown seaweed. Common features among the different genera are the pigments of chlorophylls a and c, β -carotene, violaxanthin and fucoxanthin, source of the brown color; a sugar food reserve (**laminarin**); and cell walls made up of an inner cellulose layer and an outer mucilaginous layer. Diverse size ranges from microscopic to enormous kelps up to 60 meters in length. Of the 250 known genera there are more than 900 species.

Asexual reproduction occurs by fragmentation and production of sporangia with zoospores. When a section of a living filament breaks off, the fragment becomes a new individual. A sporophyte individual produces sporangia with zoospores, that when released, develop into more sporophyte individuals.

Sexual reproduction is by sex cells (gametes) that look alike (isogamy), or are unlike (anisogamy), or by formation of motile sperm with a stationary egg (oogamy).

Of interest ... **ecosystem**: dense beds of kelp along sea coasts provide a substrate for small animals, protection, and foods for swimming animals and fish, and they contribute to phytoplankton communities; **industry**: **algin** (a cell wall constituent) contains sodium, ammonium and potassium salts (these salt compounds are used in fireproofing fabrics, as laundry starch substitutes, as ice cream stabilizers, as binders in printer's ink, in soaps and shampoos, in photographic film coatings, in paints and varnishes, and in leather finishes; insecticides; toothpaste, shaving cream, and lipstick); **fertilizer**: brown algal organisms contain more potassium, less phosphorus, and about the same proportion

of nitrogen as animal manure; **food**: species of kelps are used as food (**lombu**) in Japan.

Ectocarpales. Of the 13 orders, the most primitive brown algae are found in this order. The body (thallus) consists of erect filaments of a single row of cells (uniseriate) with basal branching systems (heterotrichy). Their size ranges from microscopic to forms up to 25 cm. long.

Ectocarpus

This alga is found on most seashores growing upon other plants (**epiphytic**). The filaments (a, b) of the alga have a filmy appearance. The cells have net-like (reticulate) chloroplasts (c). Alternate generations are represented by sporophytes and male and female gametophytes. A **sporophyte** is an individual that produces sporangia with 2n spores, while a **gametophyte** produces 1n gametes (sex cells).

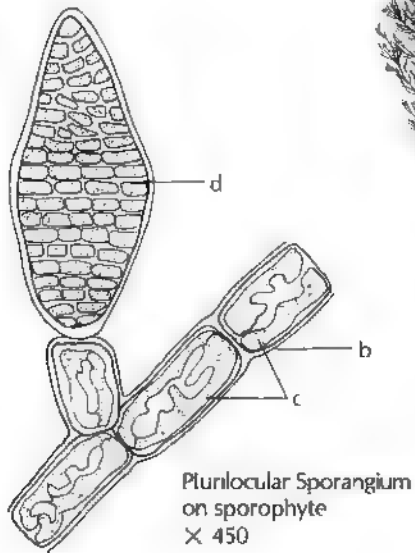
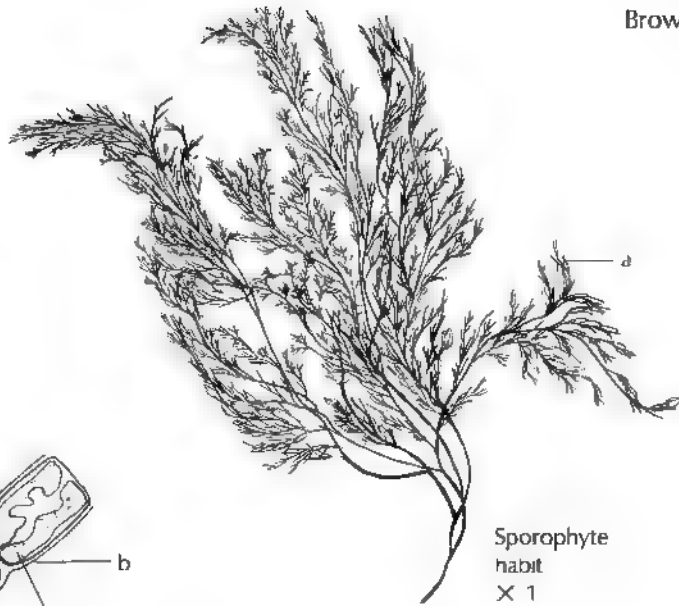
The sporophyte produces two types of reproductive structures: (1) a multicellular (plurilocular) sporangium (d) produces 2n zoospores that germinate into another sporophyte plant; (2) a unicellular (unilocular) sporangium (e) produces 1n zoospores that germinate into gametophytes. Gametophytes develop plurilocular gametangia (f) that produce motile gametes of the same sex as that of the parent. Fusion of male and female gametes results in development of a 2n (diploid) sporophyte.

If a gamete does not fuse with another gamete, it may be by parthenogenic germination produce a 1n (haploid) sporophyte. **Parthenogenesis** is the development of a new individual from an unfertilized egg. There are also other more complicated variations in the life cycle of *Ectocarpus*.

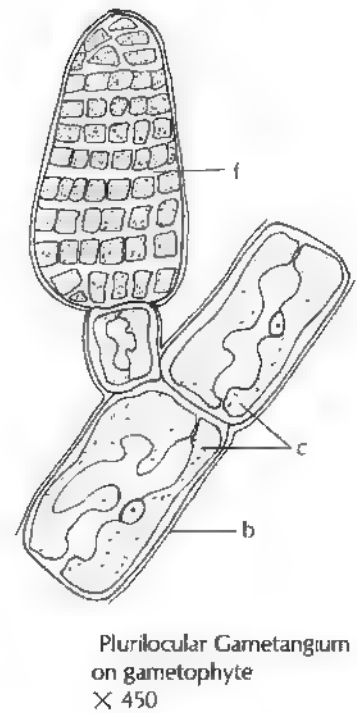
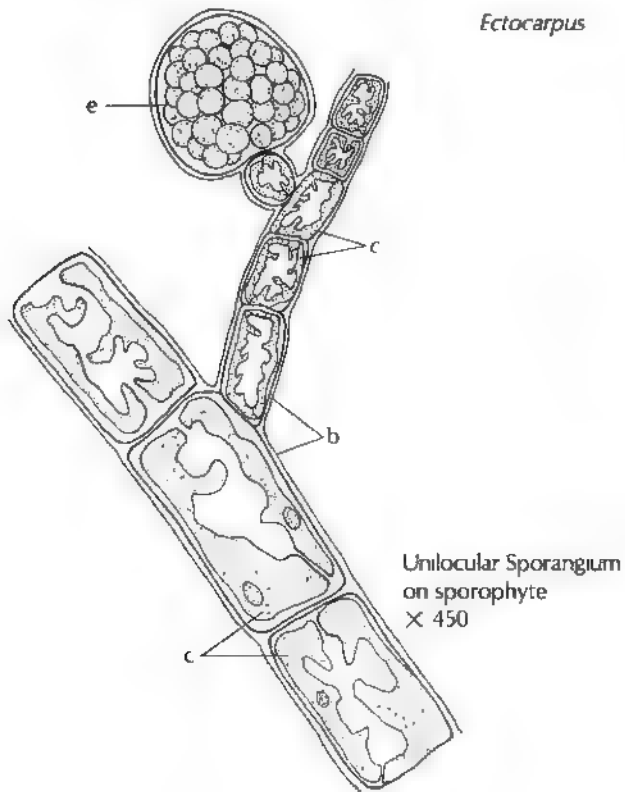
COLOR CODE

tan-green: sporophyte (a), filament (b), chloroplasts (c)
tan: sporangium (d, e), gametangium (f)

Brown Algae



Ectocarpus



Brown Algae (continued)

Laminariales (Kelps). This order consists of the kelps, the largest of all algae. Some reach 100 meters or more in length. The microscopic gametophytes have male and female gametes on separate individuals. The characteristic tissue of the sporophyte is composed of randomly arranged cells (parenchyma, for photosynthesis and food storage), rather than a continuous filament of cells.

Well-developed meristems generate new cells that contribute to growth of the sporophyte thallus in length and width. (**Meristems** are areas of undifferentiated cells that can develop into specialized tissues and organs.) The macroscopic sporophyte structure consists of a blade, stalk (stipe), and holdfast part that is attached to the rocky substrate.

Laminaria

Most species in this genus have perennial basal structures consisting of a stipe (a) and a root-like holdfast (b). There is a loss, but later replacement, of the sporophyte blade (c) from the stipe's meristematic region.

The reproductive structures of the sporophyte are asexual unilocular sporangia (d) containing zoospores (e). Between the sporangia are thread-like structures termed **paraphyses** (f), with distended tips that provide protection for the zoospores.

Nereocystis leutkeana Ribbon Kelp

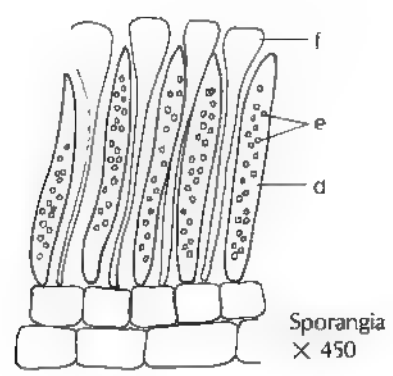
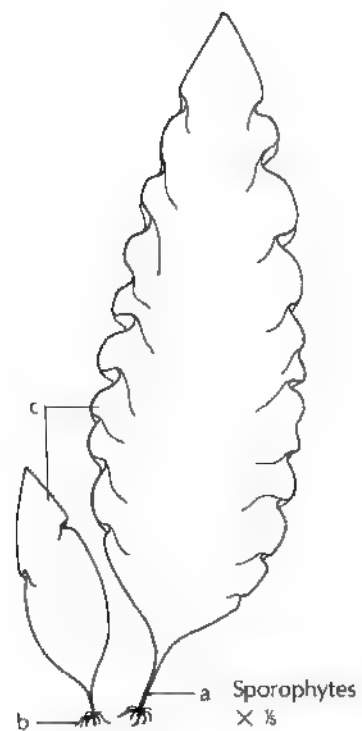
This annual kelp has blades that develop in the same manner as *Laminaria*. Due to progressive splitting, the blade (g) appears ribbon-like. The top of the stipe (h) bloats into a gas-filled **pneumatocyst** (i), which serves as a float to maintain the buoyancy of the blades at the water's surface as the stipe elongates.

Sexual reproduction is oogamous as follows: the microscopic male gametophyte produces clusters of antheridia (k) containing biflagellated sperm at the filament tips. The microscopic female gametophyte produces a non-motile egg in the oogonium (l). After fertilization, a zygote is formed which emerges from the oogonium and begins sporophyte development (m). (A **zygote** is the product of fertilization and is potentially a new individual.)

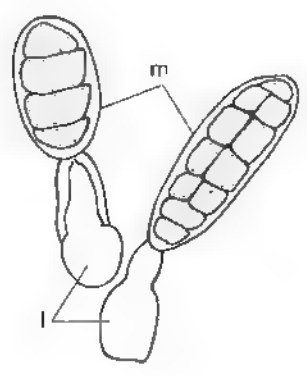
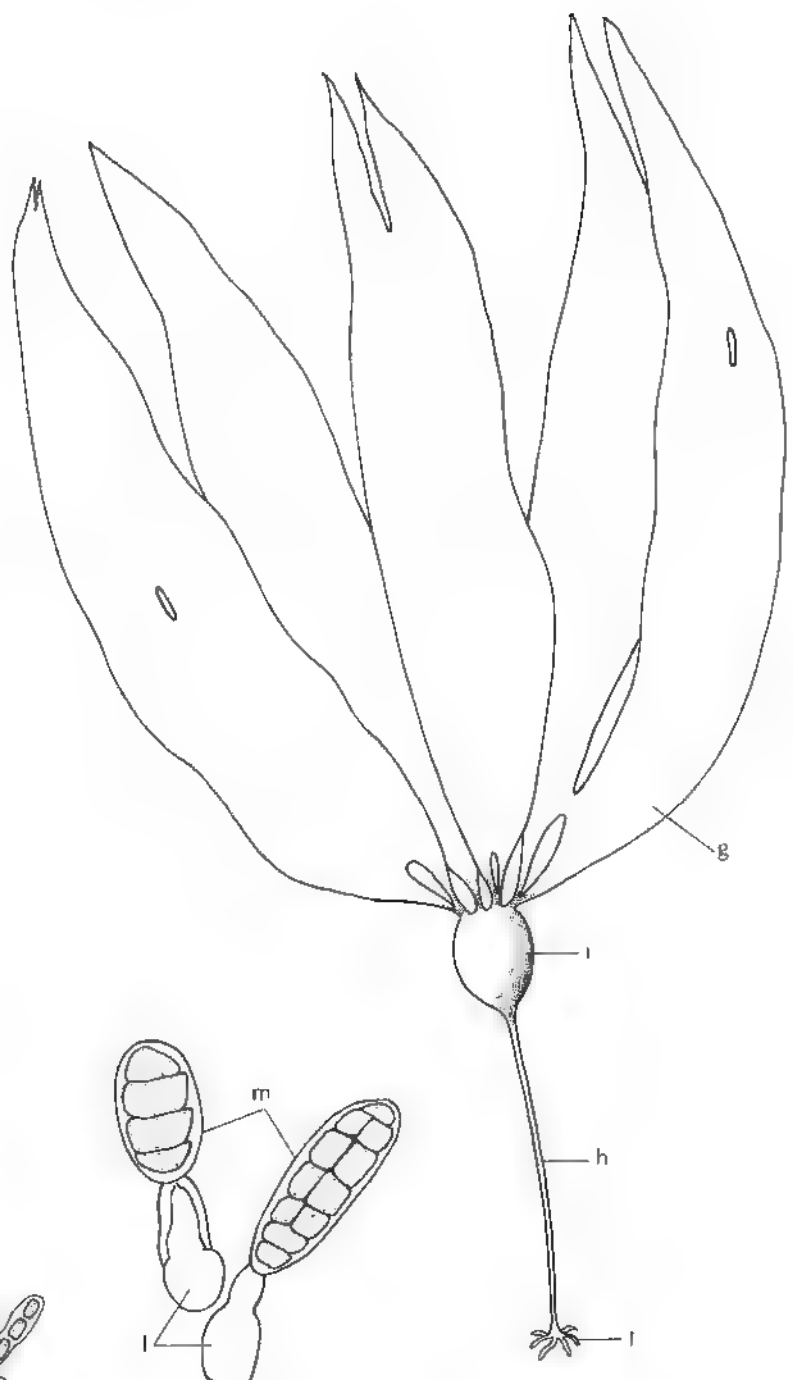
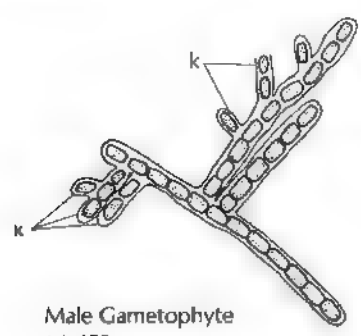
COLOR CODE

tan-green:	stipe (a), blade (c)
tan:	holdfast (b), sporangium (d), zoospores (e), antheridium (k)
white:	paraphysis (f)
yellow-brown:	blade (g), stipe (h), pneumatocyst (i), sporophyte (m)
brown:	holdfast (j)
transparent:	empty oogonium (l)

Brown Algae



Laminaria



Nerocystis leutkeana
Ribbon Kelp

Brown Algae (continued)

Fucales. The algae in this order are unique in that the gametophyte generation has been suppressed. Thus, there is only a $2n$ (diploid) organism. It has oogamous sexual reproduction by $1n$ (haploid) gametes (see below), which arise by meiosis. **Meiosis** is a process of sexual reproduction in which a $2n$ (diploid) organism produces $1n$ (haploid) sex cells (gametes) by reduction division from one $2n$ cell to form four $1n$ cells.

Fucus vesiculosus

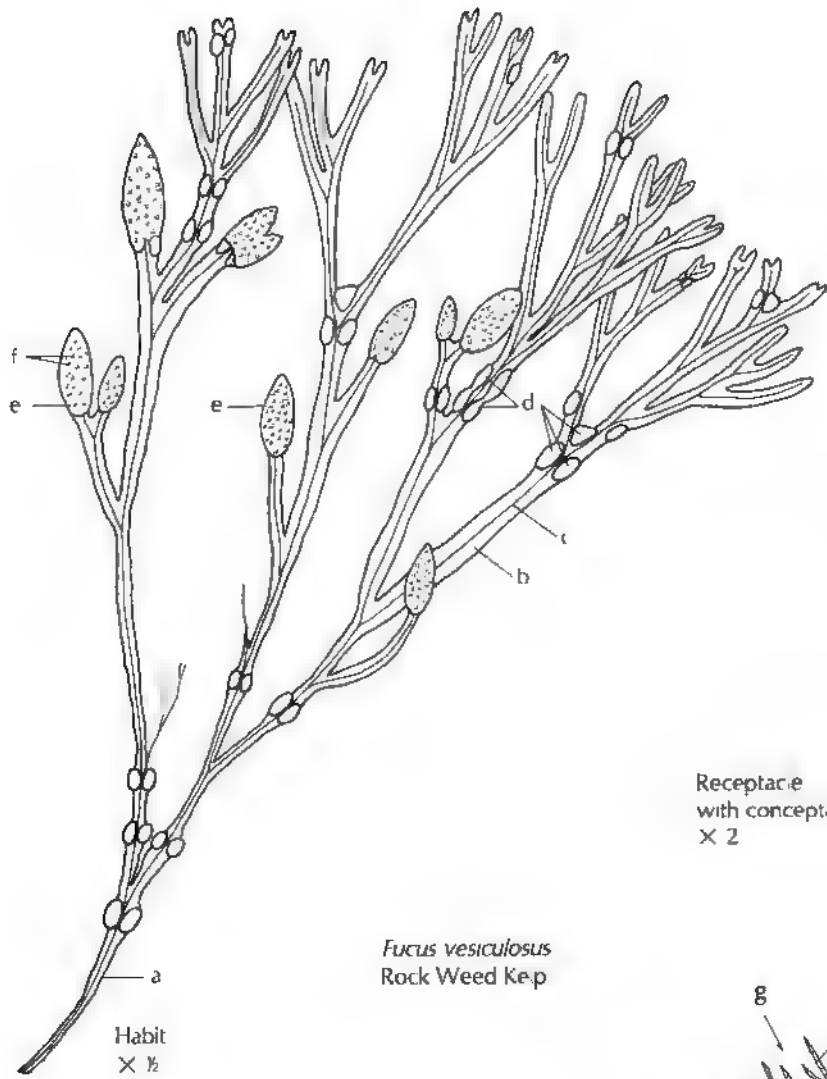
The thallus of this alga consists of a holdfast, stipe (a), and flat, bilaterally branched blades (b) with midrib (c) and paired air bladders (pneumatocysts, d). The separate male and female plants have swollen fertile areas on the blade tips called **receptacles** (e). They produce either male or female **conceptacles** (f).

A conceptacle has a pore (g) that opens from the surface of the receptacle to surrounding water. Also present in the conceptacle are sterile, hair-like threads called **paraphyses** (h), and either oogonia (i) that produce eggs, or antheridia (j), that produce biflagellated sperm. When eggs are released from the oogonium into the water, they produce **fucoserraten**, a sex attractant (pheromone), that causes the sperm to swarm around them. Fertilized eggs develop into $2n$ (diploid) individuals.

COLOR CODE

brown-red:	stipe (a), blade (b, c)
tan:	air bladders (d)
brown:	receptacle (e), oogonium (i), antheridium (j)
colorless:	conceptacle wall (f), paraphysis (h)

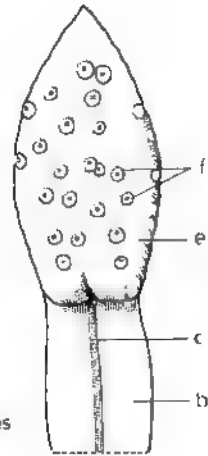
Brown Algae



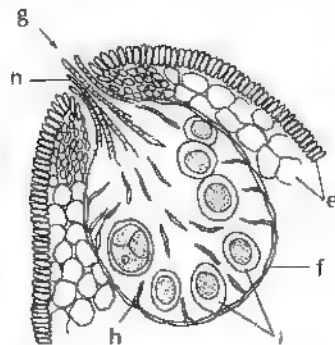
Fucus vesiculosus
Rock Weed Keap

Habit
× ½

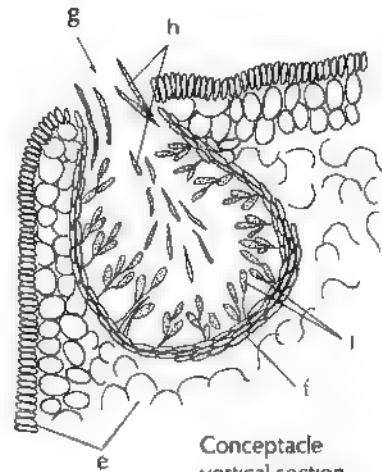
Receptacle
with conceptacles
× 2



Conceptacle
vertical section
female
× 120



Conceptacle
vertical section
male
× 120



Stoneworts

According to the fossil record, this ancient group of 6 living genera lies developmentally between the green algae and the liverworts and mosses (bryophytes). Fossils of stoneworts are found from the late Silurian period, over 400 million years ago. Stoneworts grow submerged in fresh water or sometimes in brackish (salty) water with rhizoidal attachment to the substrate of either soil or rock. With a preference for hard water (high pH), stoneworts have incrustations of calcium carbonate that account for the "stonewort" name. An obnoxious odor is characteristic of the plants.

Stoneworts grow continuously by means of a single dome-shaped apical cell that cuts off by mitotic divisions new node and internodal cells.

Their pigments are chlorophylls a and b, carotenes, and xanthophylls. Sexual reproduction is oogamous, which means a motile sperm unites with a larger, stationary egg.

Chara Stonewort

The base of this plant, the **protonema** (a), has substrate-anchoring rhizoids (b), while the upper portion of the stem (c) has whorls of branches (d) at the nodes. The stem is a long axis of cells divided into small regions (nodes and internodes). The node divides producing whorls of branches. The internode is made up of one cell containing a single nucleus. The repro-

ductive structures, male **globules** and female **nucules** (e), arise at nodes on the branches.

The male globule (antheridium) has an outer layer of sterile shield cells (f). Small cells (g) arise on the inner surface which produce antheridial filaments (h). Each cell in the filament produces a single sperm with two flagella for motility. The shield cells break open, permitting sperm cells to swim free.

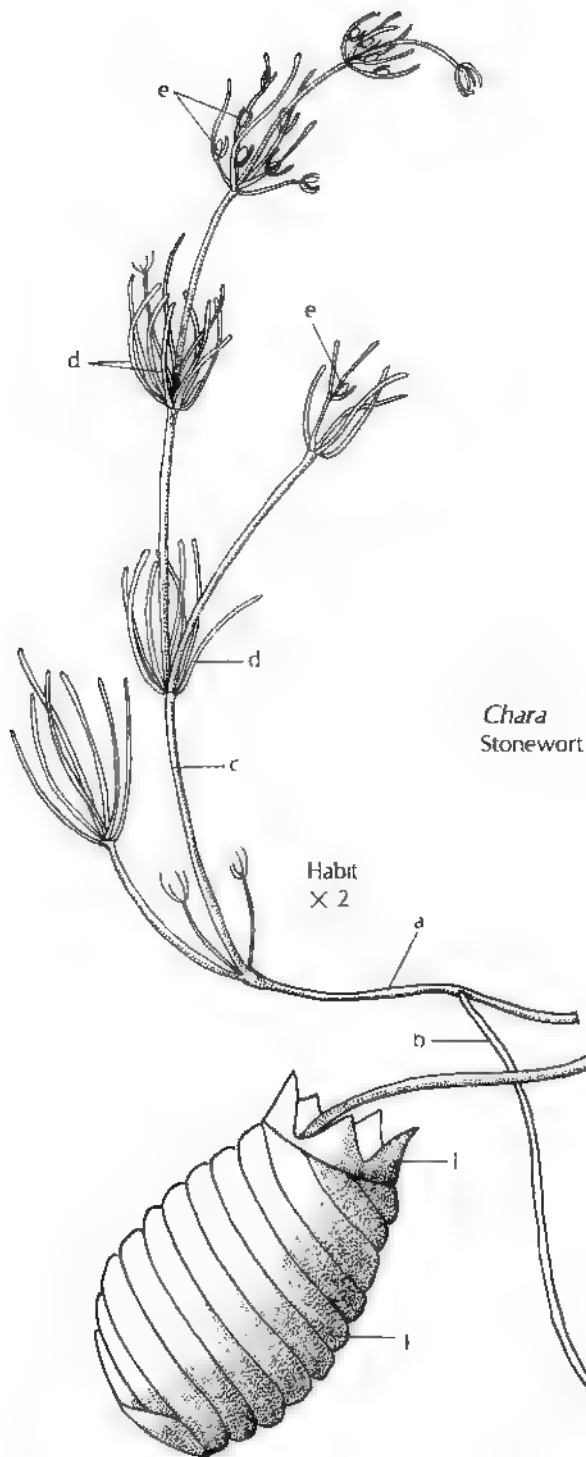
The female nucule (oogonium) is attached to a node by a short stalk-like cell (i). Sterile sheath cells (j) spiral around the single egg (k). At the top are small **coronal cells** (l). At maturity, slits that form under the coronal cells allow the sperm to enter the oogonium.

After fertilization, the sheath cells thicken around the zygote (oospore), which overwinters as a dormant structure. After germination in the spring, the zygote wall splits and the primary protonema (m) emerges to form a new sporophyte plant.

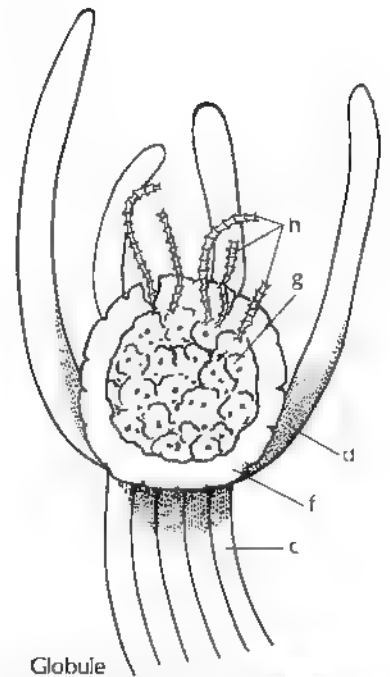
Of interest . . . **gravisensors**: barium sulfate crystals in the tips of the rhizoids sediment in the gravitational field, thus enabling the rhizoids to respond to gravity and bend downward towards the substratum (starch-filled amyloplasts in root caps of higher plants serve the same function). The large cells of stoneworts have proven to be highly suitable for **experimental study** of patterns of cell growth, orientation of cell wall microfibrils, transport of ions into and out of the cells, and cytoplasmic streaming (**cyclosis**).

COLOR CODE

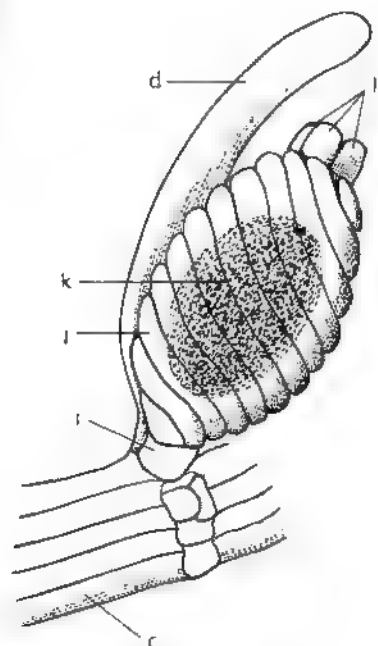
gray-green:	protonema (a, m), stem internode (c), branches (d)
white:	rhizoid (b)
red:	nucules (e), sheath cells (j)
tan:	egg (k), coronal cells (l)
colorless:	shield cells (f), filaments (h)
red-brown:	cells (g)
green:	stalk cell (i)



Germinating Embryo
X 54



Globule
crushed to show antheridial filaments
X 116



Nucule
X 54

Liverworts, Hornworts, Mosses

This most primitive group of green land plants are called **bryophytes**. Mostly perennials, the plants are small in size and have no vascular tissues. Humid habitats provide a water medium for the motile (flagellated) sperm to reach the egg. Bryophytes cannot tolerate salt water, excessive heat, or pollution. Mosses can dry down during drought, then recover with rainfall. They are also tolerant of freezing. Liverworts, on the other hand, cannot tolerate dryness, but can survive freezing.

Bryophytes have two generations. The dominant plant (gametophyte generation) develops from a 1n (haploid) spore and produces sperms and eggs. A fertilized egg forms a 2n zygote, which develops into the sporophyte. The smaller sporophyte generation produces 1n spores by meiosis that are dispersed and develop into gametophytes. In some bryophytes, asexual structures called **gemmae cups** (a) contain gemmae (b) that develop into gametophytes.

Liverworts (Hepaticae). The liverworts are primitive bryophytes. The gametophyte is flat and strap-shaped, as in *Marchantia*, or leafy as in *Bazzania*. The gametophyte body (thallus, c) branches equally (**dichotomously**).

Marchantia polymorpha

This species has unisexual thalli (**dioecious**). The male gametophyte develops antheridia-bearing stalks (**antheridiophores**, d), which produce motile sperm in its disc-shaped top. The female gametophyte develops an **archegoniophore** (e), which produces archegonia, flask-shaped structures containing eggs, under its umbrella-shaped top. After fertilization, a 2n zygote develops into a sporophyte, which in turn produces spores that develop into gametophytes.

Hornworts (Anthocerotae)

Anthoceros punctata Common Hornwort

The gametophyte thallus (f) forms a flat rosette. Male and female structures occur in the upper layers of the thallus. The union of sperm and egg produces the sporophyte. A foot (g) secures the sporophyte (h), to the gametophyte thallus. The sporophyte splits at the top into 2 valves to expose the spores.

Mosses (Musci). All moss gametophytes have 3- to 5-ranked leaves. Most mosses develop from a spore

into a thread-like structure (**protenema**) with rhizoids, then into a leafy gametophyte. The young sporophyte is green and photosynthetic. Its firm tissue eventually turns brown and may persist on the gametophyte for years. Unlike the liverworts and hornworts, mosses show a great deal of variation in gametophytes and sporophytes. Mosses form large colonies by fragmentation and gemmae.

Sphagnum centrale Peat Moss

The peat mosses (*Sphagnum*, i) grow in acid bogs. They secrete hydrogen ions, contributing to the acidity. This acid environment delays the vegetation decay process. Thus, sphagnum mosses contribute to mat formation at the open water margin of the bog. This provides a habitat for other types of plants. Undisturbed, a bog can eventually develop into a forest through the process of **succession**. Due to its great water-holding capacity *Sphagnum* peat, derived from old bogs, is added to garden soil to acidify it and hold moisture.

Andrea rupestris Rock-loving Moss

This plant is found mainly on rocky outcroppings. The leafy gametophyte (j) is branched. The sporophyte is raised on a stalk (pseudopodium, k). When the capsule (l) dries the inner walls contract into 4 slits, releasing the spores.

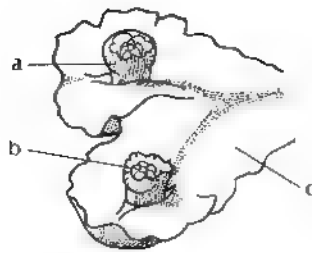
Tetraphis pellucida Four-tooth Moss

Moist rotting logs in coniferous forests provide the main habitat for this plant. Leafy gametophytes (m), attached by rhizoids (n), produce gemmae cups (o). The sporophyte is borne on a long stalk (seta, p), that twists near the capsule (q). A pleated covering (**calyptra**, r) protects the capsule; it falls off at maturity. A lid (**operculum**) opens to expose 4 teeth (**peristome**, s). When wind or animals shake the capsules, spores are released.

COLOR CODE

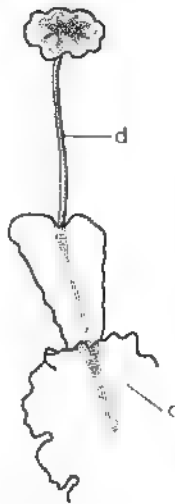
green:	gemma cups (a, o), gemmae (b), thallus (c, j, m)
tan:	antheridiophore (d), archegoniophore (e), foot (g), pseudopodium (k), capsule (l, q), seta (p), calyptra (r), teeth (s)
black:	sporophyte (h)
gray-green:	thallus (i)
white:	rhizoids (n)

Liverworts, Hornworts & Mosses

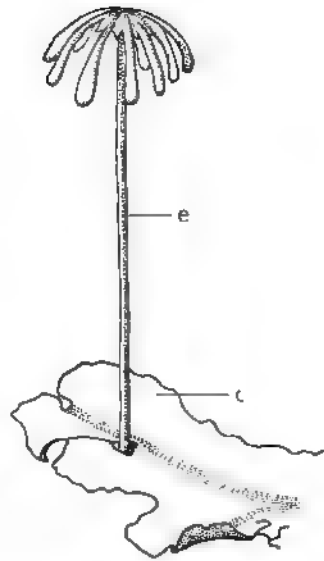


Gametophyte
with gemmae
× 2½

Marchantia polymorpha
Common Liverwort



Male Gametophyte
× 2½



Female Gametophyte
× 2½



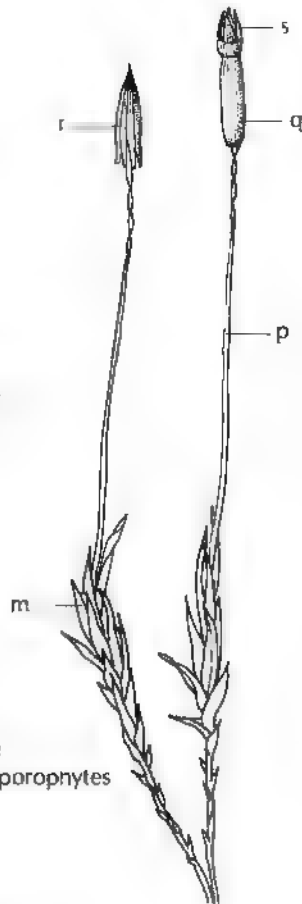
Anthoceros punctata
Common Hornwort
gametophyte at base
sporophytes above
× 3



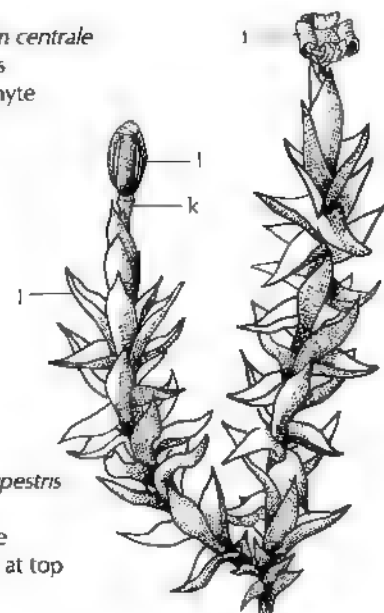
Gametophyte
with gemmae
× 6

Gametophyte
with stalked sporophytes
× 6

Tetraphis pellucida
Four-tooth Moss



Sphagnum centrale
Peat Moss
gametophyte
× 1¼



Andreaea rupestris
Moss
gametophyte
sporophytes at top
× 13

Whisk Ferns

The whisk ferns are believed to be among the most ancient of living vascular plants. There is no known fossil record to determine relationships with extinct forms. There are two psilophyte genera: *Psilotum* and *Tmesipteris*.

Characteristics. These are rootless, simple plants with rhizoids, as anchoring structures, and hairless (**glabrous**) upright stems with simple sterile appendages (**enations**). The large spore cases (sporangia) are fused into two's or three's.

Reproduction. In whisk ferns, an alternation of generations results in a dominant sporophyte plant producing alike spores (**homosporous**), which germinate to form 1n (haploid) gametophytes. The underground gametophyte, which forms mycorrhizal associations with fungi for nutrition, develops archegonia, each with 1 egg, and antheridia with flagellated sperm.

After fertilization, a 2n (diploid) zygote forms, which eventually develops into a sporophyte plant. Asexual reproductive bodies (gemmae) may be produced on the sporophyte.

Of interest . . . Whisk ferns are dominant components of the tropical ecosystems of Hawaii's island archipelago. In fact, they are considered to be weeds in Hawaii due to their propensity to colonize disturbed areas, (W. H. Wagner, Jr., personal communication).

Psilotum nudum Whisk Fern

This plant may be terrestrial or grow upon other plants (**epiphytic**) in the tropics and subtropics. The shoot is upright with stems (a) that branch into two equal parts (dichotomous branching). Simple leaf-like appendages, called enations (b), emerge from the stem. The three-lobed spore case (c) has a small, forked, leaf-like scale (d) below.

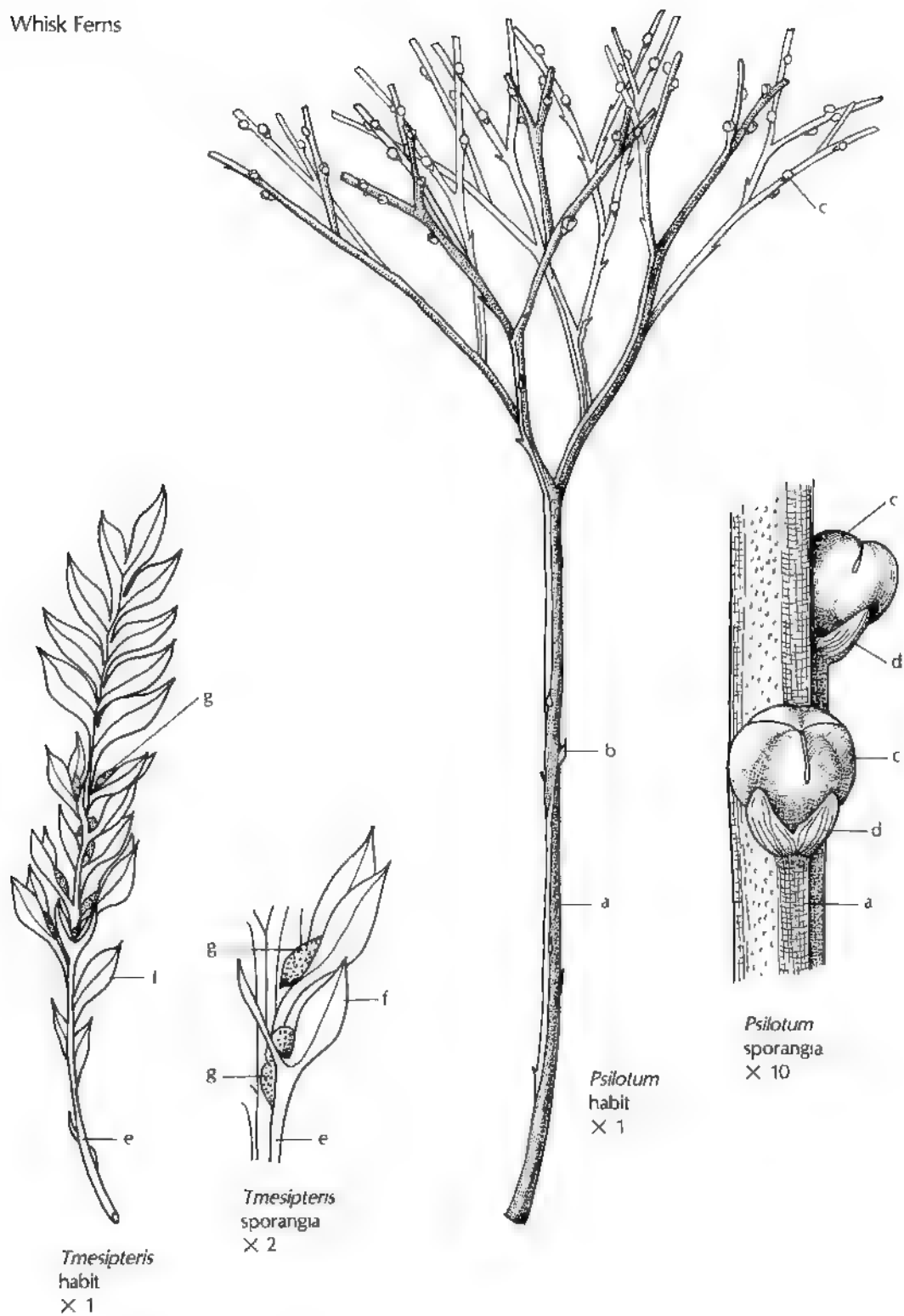
Tmesipteris tannensis var. *lanceolata*

This plant is found only in the southwestern Pacific Ocean area. It has a simple stem (e) with flat, single-veined, leaf-like appendages (f). The sporangium (g) is two-lobed.

COLOR CODE

light green:	stem (a), enations (b), scale (d)
yellow:	sporangium (c)
green:	stem (e), enations (f)
tan:	sporangium (g)

Whisk Ferns



Clubmosses, Spikemosses, Quillworts

This distinct group of ancient plants has five living genera. Common features are single-veined leafy appendages (**microphylls**), two-part branching which may be equal or unequal, axillary sporecases (sporangia), and flagellated sperm.

Clubmosses (Lycopodiales). *Lycopodium*, with 700 species, is found worldwide, with most species occurring in the tropics. Plants are herbaceous, perennial, and usually evergreen. No leaf outgrowths (ligules) are present. Some species bear sporangia in terminal spikes (**strobili**).

Lycopodium annotinum Stiff Clubmoss

The creeping horizontal stem (rhizome) of this plant has upright shoots with annual constrictions (a). The spirally arranged leaves (b) are narrow and spread in different directions. In the alternation of generations, the spore germinates into a plant (gametophyte) bearing male and female sex cells (gametes). Then, after fertilization, an embryo develops into a sporophyte, the dominant plant.

A "cone" (strobilus, c) of specialized leaves (**sporophylls**), bearing sporangia in the axils, terminates an upright shoot. The sporangia contain one type of spore (**homosporous**).

Spikemosses (Selaginellales). *Selaginella*, the single genus, has about 600 species. Differing from *Lycopodium*, there are **ligules**, root-like organs (**rhizophores**) occurring at dichotomies, and sporangia always in a "cone," bearing spores of two sizes (**heterosporous**). Reproduction is the same as shown below for *Isoetes*.

While most species prefer moist conditions, there is an unusual species, *Selaginella lepidophylla* which is called resurrection plant. It is native to dry regions of the southwestern United States and Mexico. Dry specimens of this plant are occasionally found in plant stores as a curiosity because it appears as a dried leafy mass until "revived" with water that causes it to turn green and flatten into a rosette. It can be dried and revived repeatedly.

Selaginella rupestris Rock Spikemoss

The creeping stem has spirally arranged leaves (d), root-like appendages (rhizophores, e), and 4-sided fertile spikes (f).

Quillworts (Isoetales). These plants are considered by some botanists to be the last remnant of the fossil tree lycopods due to their peculiar secondary growth, heterospory and presence of ligules. *Isoetes*, with 60 species, grows mostly submerged in lakes, ponds, and streams.

Isoetes echinospora Braun's Quillwort

The sporophyte has an enlarged perennial underground stem, the **corm** (g). The roots (h) branch dichotomously, and annual strap-shaped leaves (i) grow in a spiral cluster (**rosette**). The leaf has a ligule (j), 4 vertical air chambers (k), and an expanded fertile base covered by a flap (**velum**, l).

At the bases heterosporous leaves (**mega-** and **microsporophylls**) bear megasporangia (m) containing large spores (**megaspores**, n) or microsporangia (o) with small spores (**microspores**). The megaspore wall is variously ornamented according to species. The megaspores develop into female gametophytes, while the microspores produce male gametophytes.

Stylites andicola Andes Quillwort

This plant, forming cushions in marshes, was discovered in the Andes Mountains of Peru in 1957. The stem (p) branches dichotomously with the leaves (q) atop each section. The roots (r) develop on the sides of the stem.

COLOR CODE

dark green:	leaves (b)
green:	spike (c), leaves (d, q), ligule (j)
white:	rhizophores (e), roots (h, r), megasporangium (m), microsporangium (o)
tan:	velum (l), stem (p)
light green:	spike (f), leaves (i)
brown:	corm (g)
yellow:	megaspore (n)

Horsetails

The single genus, *Equisetum*, with 15 species, is the only present-day member of plants in this family, Equisetaceae. It is related to the fossil plant, *Calamites* (see 43). Species of *Equisetum* are found worldwide except in Australia and New Zealand.

Characteristics. These annual or perennial terrestrial plants are less than 1 meter in height, with the exception of the Costa Rican tropical *E. giganteum*, which grows to 8 meters in height. The plant consists of a jointed underground perennial rhizome and annual upright jointed shoots.

Species with branched shoots are commonly called “horsetails” and unbranched species are known as “scouring rushes” because of their earlier use as pot scrubbers (effective because of the presence of amorphous silica, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$, in the stem surface).

The photosynthetic stem is round and grooved on the outside and hollow in the center. At the stem node is a sheath of greatly reduced leaves of various teeth-like shapes, depending on the species. In branched species, whorls of branches develop at the base of the leaf sheath. Internodes of the rhizomes and aerial shoots elongate by means of basally localized intercalary meristems (see 15).

Reproduction. The plant has an alternation of a sporophyte generation with an either male or bisexual gametophyte generation as follows: The sporophyte produces a terminal “cone” (**strobilus**) with whorls of hexagonal scales (**sporophylls**) on stalks. Attached to each scale are 5 to 10 spore-bearing sacs (**sporangia**) containing alike spores (**homosporous**). The spores contain chlorophyll. They germinate within a few days, developing into tiny green thalloid gametophytes that produce antheridia with sperm or both antheridia and archegonia. Fertilization of the egg in an archegonium

by a sperm results in a zygote that develops into a new sporophyte plant.

Equisetum variegatum Variegated Scouring Rush

Equisetum stems (a) are grooved and possess hollow air channels within. The air channels include a central canal (b), **carinal canals** (c), and **vallecular canals** (d) at the bottom of each groove. Size and shape of the air canals vary with species.

Equisetum arvense Field Horsetail

This species has two forms (**dimorphic**). In the spring, an unbranched fertile shoot (e) emerges from the rhizome (f). It is short-lived and dies back when the spores are shed from the strobilus (g). The other form of stem (h) is smooth and branched (i). By summer, the branches have elongated. The leaf sheaths (j) in this species have dark, lance-shaped teeth (k).

Equisetum laevigatum Smooth Scouring Rush

The scouring rush stem (l) is unbranched. The leaf sheath (m) is flared and has deciduous teeth (n). The strobilus (o) shows the hexagonal surface of the sporophylls (p).

Equisetum hyemale Common Scouring Rush

A sporophyll removed from the strobilus exposes the sporangia (q) containing the spores.

Equisetum scirpoides Dwarf Scouring Rush

A spore (r) surface splits into 4 strips of water-absorbing (hygroscopic) **elators** (s). When dry, the elators (t) expand and aid in spore dispersal.

COLOR CODE

green:	stem (a, h), branches (i), sheath (j), sporangium (q)
colorless:	canals (b, c, d)
tan:	shoot (e), strobilus (g)
dark brown:	rhizome (f)
yellow-green:	stem (l), sheath (m), surface of sporophylls (p), spores (r), elators (s, t)

